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In copertina: Inland territory of Abruzzo on the border between the municipalities of Massa d'Albe and Ovindoli. The photo shows the valley floor characterised by agricultural fields and the mountain slopes used for grazing (photo by Enrico Lucci).
Sul retro: Coastal wetland near Margherita di Savoia (Northern Apulia) used for salt production (photo by Enrico Lucci).

Enrico Lucci

THE LIVED-IN LANDSCAPE

Spatial dimensions of human activities in central-southern Adriatic Italy during the Copper and Bronze Ages

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“*Cambia lo superficial*
Cambia también lo profundo
Cambia el modo de pensar
Cambia todo en este mundo
Cambia el clima con los años
Cambia el pastor su rebaño”
Julio Numhauser Navarro - Todo Cambia (1982)

Preface

This volume is the result of a two-year project funded under the *Young Researcher – Seal of Excellence 2022* programme (Next Generation EU). That grant gave me the chance to turn a bitter disappointment – a feeling that many of my colleagues will recognise, having themselves gone through the long waits, the hopes, and the frustration of seeing a project rejected by the narrowest of margins into a new opportunity. Mine was originally submitted to the Horizon Europe - MSCA 2021 call, and I missed the funding threshold by just a few decimals. I still recall the morning, while working on a post-doc in Berlin, when I received the email: the evaluation of my project was excellent, good enough to place me on the reserve list, but not good enough to secure the funds that would have allowed me to carry out the research abroad.

That disillusion, however, marked the beginning of a path I could never have foreseen. Paradoxically, it brought me to one of the universities located not only in the heart of the Central Mediterranean – the broad geographical focus of my research – but right within the very landscape I had set out to study. There, under the supervision of Professor Giuliano Volpe, I was able to develop the project that came to be known as MODLAND (*Modelling the lived-in landscapes of Southeast Italy during the 3rd and 2nd millennia BCE by implementing the ecoinformatic MaxEnt method*).

ModLand was conceived at a particularly difficult time, not only for me personally but on a global scale. I had just completed my doctorate and, as often happens, I was trying to find my way through the maze of uncertainty that comes with attempting to stay in academia. Then, only a few weeks after my PhD defence in February 2020, the pandemic began. While I have always been fascinated by quantitative and computer-based approaches in archaeology, I have also sought to shape my profile through fieldwork. I have been fortunate to take part in many projects in Italy and abroad that have enriched my experience. But during the pandemic, planning any kind of practical activity – in the field, in storerooms, or in laboratories – was far from simple. To build such components into a project proposal meant taking on the risk that they could not be carried out at all, especially within the tight timeframe of an MSCA fellowship.

So I decided to design a landscape archaeology project that relied on published data, with the aim of exploring how places were used and how they gained meaning in the landscapes of Southeast Italy during Late Prehistory, between the Copper Age and the Bronze Age.

The chapters that follow present the development of this research. But beyond the scientific aspects, this project has also been, for me, a path of reflection on the discipline itself and on the cultural trajectories that are active within it. The reader will therefore encounter in these pages both criticism and self-criticism. Alongside quantitative analysis and modelling, I have tried to pursue a more dialectical reflection on the behaviour of the communities whose lived landscapes are at the heart of this study. I should say at the outset that I no longer have much faith in large-scale quantitative models, even though they will be found in this work and have been central to my reflections on their effectiveness in historical reconstruction. They can certainly provide insights, but one must be careful not to mistake them for 'History'. What I do find meaningful is to unravel the countless scenarios of human diversity in action. Within that mosaic of differences, patterns do emerge, and details intertwine to form wider stories, sometimes even systemic ones. But that, to me, is a very different thing from treating data as a kind of highly refined fuel for digital engines.

Over these last years I have met and worked with many colleagues, both in my host institution and outside, and I am grateful for the exchanges that have enriched me. Among them, I wish to mention in particular the many doctoral candidates and students I have had the privilege of working with, whose questions, curiosity, and energy have been a constant source of inspiration.

1. Introduction

How late prehistoric societies interacted with their landscapes – the physical components of their environments, the processes through which these became places, and the changing meanings they held across different communities and periods – forms the key question addressed in this work.

As a paleoethnologist, my focus is not on generating new ecological knowledge about past environmental transformations or human alterations of ecosystems – a theme that rightly occupies a central role in contemporary scientific and social debates. Although these aspects are considered and discussed, the primary emphasis lies on the *lifeworld* [1]: the structure through which elements of the surrounding physical world were meaningfully related within changing human behavioural patterns. This perspective is explored through computational methods designed to explore such dynamics under conditions of archaeological uncertainty – that is, the fragmentary, uneven and often biased nature of the available record, where evidence is incomplete, chronologies are approximate, and data quality varies considerably across sites and regions. Yet, these methods are integrated within a contextual interpretive framework, in which quantitative models are treated as heuristic tools – open to generating scenarios rather than definitive answers – and are subjected to critical testing against the contextual complexity of both the data and the diverse ways in which landscapes may have been conceived and experienced by past human groups, dimensions that cannot be directly measured but can only be approached through interpretation.

From a social perspective, the landscape acts as a meaningful medium, reflecting the mutual influence between people and the material world. A place can be conceived as a '*relational concept*' [2], embedded in human behaviour, and thus the landscape becomes a network of such places. Across centuries of philosophical debate, various authors have proposed categories for structuring reality, with particular emphasis on objects, properties, and events. In this perspective, a landscape cannot be understood merely as an 'object' or a bounded entity. Rather, it is better conceived as an ontological item that emerges through relations: it is composed of objects (sites, features, artefacts), properties (environmental conditions, topographies), and events (practices, movements, transformations).

Different human groups may have perceived these places in diverse ways across space and time. Exploring this diversification is crucial to understanding past societies, since interactions with surroundings represent material expressions – in actual space and on the ground – of intertwined social dimensions.

The analysed chronological and geographical context was a specific macro-region of the Central Mediterranean, the southeastern Italian peninsula between the 4th and 2nd millennia BCE [3], which offers an extremely diversified ecological framework and diversification of cultural trajectories both over time and space. This chrono-geographical setting captures the transformation of settlement patterns between the Copper Age to the significant development of long-lived settlements during the Bronze Age [4], exemplified by fortified centres [5].

Despite the significance of these processes, large-scale analyses remain scarce in Italian prehistory. This project seeks to fill that gap, highlighting the importance of exploring dynamics at both macro- and local-scales. The decision to experiment with large-scale [6] spatial data analysis provides new insights into how settlement patterns developed within, and adapted to, diverse environments, thereby shaping ecological niches [7].

The dataset comprises excavated open-air sites – including settlements and associated functional areas such as cooking structures, which indicate human activity – as well as sites identified through surface collections. Sources include published literature and recently available online datasets (e.g. cartapulia.it).

[1] Heidegger 1962.

[2] Cosgrove 1984; Thomas 2001.

[3] From its initial conception, the chronological framework has been expanded to encompass the entire Copper Age.

[4] Lucci 2025.

[5] Cazzella and Recchia 2018; Iacono *et alii* 2021.

[6] Whitley 2017.

[7] Laland and Brown 2006.

Caves were excluded from the modelling process due to their varied use over time, though they have been considered in the local contextualisation of data (Chapter 5). The dataset is primarily intended to investigate long-term settlement transformation strategies across a wide area. Surface collections were included on the basis of published reports; however, details such as sherd counts or densities are rarely specified, except in a few systematically surveyed contexts. For this reason, minimum thresholds of artefacts were deliberately avoided, as they would have drastically reduced the dataset and hindered the comprehensive investigation of long-term dynamics. Instead, the significance of each find has been evaluated according to its specific context. This approach allows for an in-depth exploration of human interactions within the landscape without imposing arbitrary restrictions, while also acknowledging inherent uncertainties.

The methodological framework combines traditional GIS analyses with species distribution modelling (SDM), in particular the machine learning technique MaxEnt, which forms the core tool of this research [8].

MaxEnt is a machine learning method used to make predictions or inferences from incomplete presence-only data, which includes points where a spatial phenomenon has been observed. Based on the principle of Maximum Entropy, it advocates selecting the probability distribution with the highest entropy among all that meet the given constraints. While MaxEnt is widely used in ecological analysis and species distribution modelling, its utility extends to other spatial phenomena and is even employed in natural language processing. In this research, MaxEnt modelling is applied to analyse spatial data, forecasting potential settlement locations and probing the ecological factors that influenced human settlement patterns over time. Its ability to handle presence-only data makes MaxEnt an innovative tool for predicting past human occupation in regions where traditional archaeological data may be sparse or incomplete.

Several methodological challenges were addressed: first, the use of eco-informatics analysis not merely as a proxy for environmental reconstructions, but as a way of investigating the ecological conditions within which cultural dynamics unfolded; and second, the application of MaxEnt at a regional scale, thereby testing the transferability of a technique more commonly employed in large-scale (continental) studies.

This approach embraces, and simultaneously challenges, the inherent uncertainties of territorial legacy data. It attempts to organise spatial points – each characterised by diverse quantitative and qualitative attributes – into a coherent structure that both interrelates these points and connects them with external factors such as climate and environmental conditions. In this sense, models are tools for examining the range of possibilities associated with human dynamics in the landscape [9]. Broad-scale models highlight general trends but cannot fully capture the complexity of human-landscape interactions over time. Therefore, alongside such models, a holistic contextual analysis of specific territorial case studies has been conducted to investigate transformations at multiple scales and to test the robustness of broader interpretations.

Finally, the interpretive framework of this research is informed by Niche Construction Theory (NCT) [10]. NCT highlights how human groups actively modified and transmitted ecological settings, rather than simply adapting to them. In this perspective, settlement patterns are seen as the cultural outcomes of long-term practices that reshaped environments and created new conditions for future generations. This provides a bridge between ecological modelling and cultural interpretation, ensuring that the patterns identified here are understood not as deterministic responses, but as expressions of human agency in the construction of lived landscapes.

1. Landscape dimensions in this work

Let me begin with a premise: endeavouring to achieve a unique conception of landscape is an exercise condemned to be unfruitful from the start. The multitude of interpretations this concept can adopt merely reflects the perceptions of relationships that an individual – or more aptly for this discussion, groups of individuals – sets with the surrounding physical world, pertaining both to organic and inorganic elements [11]. It naturally follows that in such dynamics, both the shared ideological aspects, from individual to communal scale, exert a particularly significant influence. Given that the individual scale is largely inaccessible when discussing prehistoric societies, this

[8] Farashi and Alizadeh-Noughani 2023; Phillips and Dudík 2008.

[9] Llobera 2012, p. 505.

[10] Odling-Smee 2024.

[11] David and Thomas 2008; Thomas 2001.

work focuses on the social scale perspective, an obvious sentence but it is good to restate it.

Investigating the landscape dimensions in past human societies means dealing with two levels of analysis. There is a mechanistic dimension, the concept of human-environment interaction. It has gained recognition in the current scientific debate over different disciplines, including archaeological studies, prompted by the awareness of human footprints on ecosystems' life. Its aim is to understand how mechanisms regulating human societies interact with and alter those governing ecosystems. This perspective serves an *etic* view. This is also probably because the process of objectification facilitates the measurement and quantification of phenomena. From an epistemological perspective, it is insightful and enables the construction of empirical data upon which to structure the analytical process. In this approach, understanding the processes of livelihood production and consumption, along with the related exploitation of natural resources, is central. Key questions include: What places were exploited? What type of economic activities were performed there, and how significantly did these practices physically impact those places?

This approach leads toward the reconstruction of 'interactions'. Yet, in semiotic terms, interactions serve as 'signifiers', which mere economic activities do not sufficiently explain. Such communities were not solely driven by materialistic aspects of livelihood. Bearing in mind Sahlins' lesson that "*Rather than a distinct and specialized organization, 'economy' is something that generalized social groups and relations, notably kinship groups and relations, do*" [12], it follows that interactions between places are the transliterations, expressed in actual space and on the ground, of intertwined spheres of social aspects. The meaning of these 'interactions' – the 'signified' in semiotic terms – is expressed not only by the activities performed there but also by the significance of those activities within the cultural system, as well as their timing and how they are interwoven with the entire sphere of societal practices.

In *The Temporality of the Landscape* [13], Tim Ingold begins the paper by explaining what the landscape *is not.* He differentiates landscape from land (which is quantifiable and homogeneous), space (a conceptual abstraction often linked to cartographic representations), and nature (often framed in opposition to human intervention). As stated by the author [14] "*In short, the landscape is the world as it is known to those who dwell therein, who inhabit its places and journey along the paths connecting them. Is it not, then, identical to what we might otherwise call the environment?*". He depicts the landscape as qualitative, heterogeneous, and deeply connected to human perception and experience. Ingold supports a perspective where *landscape* and *temporality* – understood as *taskscape*, which capture the dynamic, rhythmic patterns of human activities [15] – are intrinsically linked through the concept of *dwelling*. This perspective has profoundly shaped my exploration of the significance of landscapes for societies under scrutiny.

A further interesting point of view is depicted by Eric Hirsch [16]. The author has emphasised in his introduction to *The Anthropology of Landscape – Perspective on Place and Space* the notion of landscape as a relational and processual category rather than a static backdrop – a view commonly held across disciplines in the late 20th century. However, embedded in his words there is a further perspective, "*'landscape' entails a relationship between the 'foreground' and 'background' of social life*" [17]. The *foreground actuality* refers to the immediacy of everyday practices and lived places, while the *background potentiality* evokes horizons of meaning and possibility that extend beyond daily experience. Hirsch further stresses that these poles "*exist in a process of mutual implication, and as such everyday life can never attain the idealised features of a representation*" [18]. This dialectic between actuality and potentiality can also be expressed through related conceptual pairs – *place/space, inside/outside, image/representation* – which highlight how landscape is constantly produced in the interplay between lived practice and imagined possibility. In this sense, landscape is best conceived as a cultural process that relates "*'us the way we are' to 'us the way we might be'*" [19].

Exploring the *emic* dimension related to the ideological sphere is accessible in studies of living societies, yet understanding the social patterns of behaviour of prehistoric societies and their mutual influences with the environment is complex. These aspects

[12] Sahlins 1972, p. 76.
[13] Ingold 1993.

[14] *Ibidem*, p. 156.
[15] *Ibidem*, p. 158.
[16] Hirsch 1995.
[17] *Ibidem*, p. 22.
[18] *Ibidem*, p. 23.
[19] Hirsch 1995, p. 24.

cannot be directly measured, classified, or quantified empirically. Does this mean we should ignore this dimension entirely? I chose not to, recognizing that while quantification provides empirical data for understanding economic activities, site densities, the impact of environmental variables, and other factors, it is still possible to construct *scenarios* that capture the cultural meanings connecting people and places, despite the inherent uncertainties of such research. Thus, my investigation was based on a quantitative-dialectic approach, combining empirical modelling with contextual interpretation. Within this framework, Niche Construction Theory provides a theoretical foundation to connect the measurable ecological interactions with the cultural strategies through which prehistoric communities transformed and inherited their landscapes.

This is why the work is centred around the concept of the "lived-in landscape", integrating economic, ecological data with archaeological and anthropological insights, which explore:

an economic perspective: places where primary economic activities such as agropastoral practices, fishing, hunting, and gathering of natural resources, including both biotic and abiotic elements, were performed, all adapted to local ecosystems;

a social perspective: places used for exchange goods and political practices, serving as nodes where social interactions occur, permeated with collective memories and meanings, contributing to the construction of a sense of belonging an intra and inter-community scale;

a cognitive perspective: the influence of landscapes on human behaviour, shaped by perceptions of their biotic and abiotic physical components;

temporality: temporal patterns related to the interactions between people and places.

2. Landscape archaeology, inductive modelling and machine learning

This section outlines why inductive modelling is particularly suitable within a landscape-archaeology perspective. The objective is to formalise broad patterns of human-landscape interaction under conditions of uncertainty, while maintaining an interpretive reading of social practices. Technical parameters and evaluation metrics are discussed in Chapter 4, while Chapter 5 develops the contextual re-interpretation of model outputs through case studies.

Landscape archaeology has expanded considerably over the past six decades [20]. Starting from the 1960s, Anglo-American New Archaeologists and palaeoeconomists laid the foundations of the field by stressing systematic mapping of archaeological sites in space and time, and their systemic connections to population dynamics, carrying capacity, and subsistence strategies [21]. Since the 1980s, developments in social archaeology and cultural geography have challenged the view of landscape as a neutral backdrop to human action, instead emphasising its role as an active medium in the mutual shaping of people and the material world [22].

Alongside theoretical developments in the discipline, landscape archaeology has benefited from methodological advancements, particularly through the application of geospatial analysis in archaeological inquiries. This approach enables a new perspective on spatial data, formalising spatial distributions, uncovering hidden relationships, handling vast amounts of data from intrasite to macro-regional scales, and visualising them effectively [23]. The widespread use of informatics tools for data processing has been central to this process.

Since the 1990s, with the advent of GIS technology, landscape archaeology has grown significantly, enhancing our ability to process archaeological and environmental data of various natures [24]. Currently, archaeological research is experiencing a significant leap forward with the introduction of AI-based analysis and enhanced capabilities for handling spatial data [25]. At the dawn of this new era in computer science applied to archaeological research, landscape archaeology is one of the branches designed to benefit most from these tools. For example, remote sensing analysis, which exploits satellite and LiDAR imagery, is experiencing a moment of particular development [26].

A further application of AI-based methods, particularly Machine Learning (ML), has created new possibilities for integrating ecological and archaeological

[20] David and Thomas 2008; Parcero-Oubina *et alii* 2014.

[21] Barker 1995; Binford 2001; Flannery 1976; Glassow 1978; Higgs 1975.

[22] Cosgrove 1984.

[23] Barceló 2002; Bivand *et alii* 2013; Blankholm 1991; Hietala and Larson 1984; Hietala and Stevens 1977; Hodder and Orton 1976.

[24] Howey and Brouwer Burg 2017; Menéndez-Marsh *et alii* 2023; Moscati 1998; Whitley 2017.

[25] Gattiglia 2025.

[26] Canedo *et alii* 2024; Casini *et alii* 2023, p. 2; Landauer *et alii* 2025.

data. In particular, the use of Species Distribution Modelling (SDM) in archaeological research is opening unprecedented opportunities for predicting and interpreting past human-environment interactions with greater accuracy and detail [27]. This ecological approach has been central to the research presented here, where MaxEnt is applied to explore settlement dynamics during the Copper and Bronze Ages of the study area, on the basis of selected environmental variables.

Within this framework, inductive modelling assumes particular importance under conditions of archaeological data uncertainty: it enables the identification of patterns from incomplete or uneven data without reducing human choices to deterministic causal chains, and provides a foundation for testing broad scenarios against contextual evidence [28]. In this sense, the models are not treated as final outcomes but as heuristic tools for interrogating human-landscape relations.

MaxEnt, short for Maximum Entropy, is a Species Distribution Modelling (SDM) technique designed to make predictions or inferences from incomplete presence-only data – that is, points where a spatial phenomenon has been observed, such as species occurrences in ecological studies [29]. The method is based on the principle of maximum entropy, which holds that, when selecting a probability distribution, one should choose the distribution with the highest entropy among all those that satisfy the given constraints. While widely employed in ecological research, MaxEnt has also been applied to other spatial phenomena and even to fields such as natural language processing [30]. In landscape archaeology, it is particularly valuable because it requires minimal assumptions about missing data, providing a robust approach for identifying likely locations of past human settlements – such as in this study – through the integration of environmental variables and known archaeological site data.

A recent volume by Robinson, Harris and Codding brings together a series of contributions that provide a broad overview of current applications of ecological approaches to the study of human behaviour in the construction of cultural landscapes [31]. As the authors note in the opening chapter, however, the theoretical and methodological foundations of this line of research lie in earlier works of the 1970s, and in particular in the influential studies of M.A. Jochim [32], which emphasised the importance of predictive models for assessing the probability of human activity in different areas. Jochim stresses the centrality of an ecological approach, as a primary framework for understanding the interactions between humans and their natural environment within an ecosystem model. While this approach prioritizes ecological factors, it does not dismiss the significance of non-environmental elements such as technology and cultural values. These factors influence the perception and use of natural resources, distinguishing the ‘cognized’ or culturally defined environment from the one an ecologist might observe [33]. Broadly speaking, this approach aligned within the theoretical framework of New Archaeologists – Binford expressed particular appreciation for the Jochim’s work [34].

In this research, the application of MaxEnt has been specifically tailored [35] to model settlement dynamics according to selected environmental features. This approach goes beyond simply mapping known site locations: it also identifies areas that could have potentially hosted settlements, thereby challenging research bias and advancing the analysis of settlement patterns in south-eastern Italy – and in the Central Mediterranean more broadly – towards new analytical frontiers.

Such an approach, while grounded in ecological modelling, requires a theoretical framework capable of linking environmental dynamics with the cultural practices that shaped and transmitted them. For this reason, the next section turns to Niche Construction Theory (NCT), which provides a conceptual bridge between modelling results and the interpretation of long-term human engagement with landscapes.

3. Niche Construction Theory (NCT)

Niche Construction Theory (NCT) has gained substantial popularity in the social sciences over recent decades. At its core, NCT describes the process by which organisms actively modify their environments,

[27] Fusco *et alii* 2024; Leonardi *et alii* 2024b.

[28] Deterministic models assume direct causal links between environment and behaviour – for instance, that water or fertile soils necessarily explain settlement. Such an approach risks reducing human choices to mechanical responses. Inductive modelling instead highlights probabilistic trends, acknowledging variability and alternative decisions shaped by cultural or symbolic factors. This provides a more flexible basis for interpreting human–landscape interactions.

[29] Elith *et alii* 2011; Phillips and Dudík 2008.

[30] Berger *et alii* 1996.

[31] Robinson *et alii* 2023.

[32] Jochim 1976.

[33] *Ibidem*, p. 9.

[34] Binford 1978.

[35] Llobera 2012.

thereby altering both the ecological conditions they inhabit and the selective contexts within which subsequent generations operate [36]. In his recent work *Niche Construction: How Life Contributes to Its Own Evolution*, the title itself evocatively captures the theoretical framework of NCT, Odling-Smee (2024) provides an in-depth treatment of the theory and its application to human-induced environmental transformations, emphasising the central role of intentional agency by individual organisms in driving evolutionary processes.

This perspective emerged in the 1980s [37] as a theoretical response to Standard Evolutionary Theory (SET), which had traditionally emphasised a linear causality between organisms and the independent selection pressures of their environments. In the following decades, NCT gained increasing interdisciplinary attention, with applications extending beyond biology and ecology to fields such as archaeology and anthropology [38].

In 1983, R. Lewontin critiqued the notion of passive adaptation, highlighting the active role organisms play in modifying their surroundings to enhance survival and reproduction, thereby influencing the selective pressures that shape their evolutionary trajectories. The formalisation of "niche construction" as an evolutionary process was largely developed by evolutionary biologist J. Odling-Smee, who also systematised the concept of "ecological inheritance" – the transmission of environmentally induced modifications across generations – in 1988. The primary mechanisms behind environmental transformation and coevolutionary trajectories in NCT are *perturbation* and *relocation* [39]. Perturbation refers to changes that organisms actively induce in their environment – sometimes intentional, but not necessarily so – with consequences for their own survival and reproduction. Conversely, the concept of 'relocation' describes the movement of organisms to new environments and their subsequent establishment in these new habitats. This process has the effect of altering the ecosystems in which the organisms become established and of spreading the impact of the organisms beyond the boundaries of their original niche.

But why has such an approach been progressively adopted in the social sciences, and particularly in archaeology? Transferring theoretical frameworks across disciplines typically requires adapting them to the specific questions, data, and methodologies of the new field. Such shifts are often driven by the need to intertwine disciplinary knowledge and to integrate new methodological tools – for example, the increasing use of computational modelling in archaeology, such as MaxEnt, to process large spatial and environmental datasets and to explore patterns that would otherwise remain hidden. This process often calls for the development of new conceptual categories to frame events, dynamics, and behaviours. Beyond explaining human actions, theory here also serves as a conceptual instrument, sharpening how we interpret the complex interactions between people and their environments across diverse contexts [40].

To catch the *fil rouge* – or at least one of the main lines of application – between NCT and archaeological studies, it is essential to reconsider the concept of ecological inheritance, within which cultural inheritance plays a pivotal role [41]. Through cultural practices such as realising settlements, clearing land, or developing agropastoral strategies, humans transmit modifications across generations, thereby reshaping the ecological niches in which they live. In this sense, cultural inheritance makes humans the 'ultimate niche constructors', capable of profoundly transforming their environments [42]. This perspective highlights why NCT has found a certain resonance in archaeology: it provides a framework for understanding long-term anthropogenic processes and the cumulative construction of landscapes as cultural-ecological niches [43].

Although the outcomes of human interactions with ecological factors have long been explored under broader notions of 'culture' [44], the value of NCT lies in formalising these dynamics within a coherent framework, emphasising mechanisms such as ecological inheritance and feedback processes, these latter refer to reciprocal dynamics between human action and modified environments.

[36] Odling-Smee 2024, p. 69.
[37] Laland *et alii* 2016; Lewontin 1983.
[38] Boivin *et alii* 2016; Laland and Brown 2006; McClure and Kennett 2023; Odling-Smee 1988; Quintus and Allen 2023.
[39] Laland *et alii* 2016; Odling-Smee *et alii* 2003.
[40] Godfrey-Smith 2000; Spengler III 2021.
[41] Odling-Smee and Laland 2011.
[42] Smith 2007.
[43] Boivin *et alii* 2016; McClure and Kennett 2023.
[44] Spengler III 2021.

2.
The environmental and archaeological background

This chapter provides the geographical, environmental, and cultural background for this research. It outlines the physical geography of the study area, the main Holocene palaeoenvironmental transformations, and the chrono-cultural trajectories between the 4th and the 2nd mill. BCE. Presenting this background is essential both for understanding how the analyses were designed and for establishing the interdisciplinary basis on which their results can be interpreted.

This overview also highlights the dynamics and variability of the study area itself. By acknowledging these dimensions, together with the biases and limitations of the available evidence, the chapter lays the groundwork for building interpretative models that are not merely mechanistic reconstructions, but contextual readings of long-term human-landscape interaction.

1. The study area: a geographical overview

Southeast Italy is part of the broad geographical area of the Central Mediterranean. The study area stretches from the Apennine backbone of the peninsula to the Adriatic coast, embracing both the mountainous hinterland and the coastal plain that opens onto the Adriatic and Ionian and more broadly the western Mediterranean (fig. 1).

It is a patchwork of diverse landscapes (fig. 2). In the north, mountainous reliefs dominate: the highest peaks of the Apennines are flanked by intramontane uplands, wetlands, and broad valleys in Abruzzo and Molise (figs. 2A-B). A distinctive feature of the deep valley that cuts across Molise is the presence of rocky spurs that rise as prominent landmarks (fig. 2C). Along the coast, a narrow strip of flat land is enclosed by the undulating hills of the Sub-Apennine zone.

Further south-east, the scenery changes entirely. The Apennine range bends towards the Tyrrhenian Sea, giving way to the Tavoliere plain in northern Apulia, the second-largest lowland of the peninsula (figs. 2E-F). South of the Tavoliere plain lies the karstic plateau of the Murge, an extensive upland stretching from the Adriatic towards the Ionian and the pre-Murgian depression. It rises gradually inland from the Adriatic side, while the southern slopes descend more steeply (fig. 2D). The plateau is conventionally divided into north-western and south-eastern sectors, with the north-western '*Alta Murgia*' forming the highest part. The calcareous nature of the plateau has favoured the widespread development of karstic features, from pitted and grooved rock surfaces to large dolines (*puli*), sinkholes, and chasms. Surface water flow is rare and usually ephemeral, as rainfall rapidly drains into swallow holes and natural depressions. Beyond the karstic depression of the Soglia Messapica lies the Salento peninsula, where the land flattens into a low-lying landscape characterised by rocky shores and sea-facing cliffs.

Geomorphology of the study area can be synthesised into six main units [1] (table 1).

During the mid- to late Holocene the landforms of the region underwent marked changes, shaped both by natural processes and by intensive human activity. Along the Adriatic and Ionian coasts the relative sealevel stood several metres below the current level, as demonstrated by centralMediterranean paleogeographic models and by submerged sites [2]. Moreover, accumulation and erosion phenomena shaped sandy shores, coastal wetlands and rocky cliffs [3].

Apulian coast was characterised by the presence of extended coastal lagoons which represented focal ecological zones for the development of human settlements from the early Neolithic to the Iron Age and successive historical periods [4]. A well-studied example is the Salso lagoon, south of the Gargano promontory (fig. 3). Now reclaimed, it once formed a broad contiguous water body – comparable to the lagoons still found north of the Gargano – delimited to the east by dune ridges intermittently breached to allow access to the open sea. Progressive fluvial sediment input from the hinterland drove incremental infilling, bathymetric shallowing and the reconfiguration of lagoonal margins. Further contexts are the areas

[1] Giraudi 1989; Tropeano *et alii* 2023; Vezzani *et alii* 2010.

[2] Bailey *et alii* 2020; Lambeck *et alii* 2004.

[3] Boenzi *et alii* 2006; Margiotta and Sansò 2025; Susini *et alii* 2023.

[4] Boenzi *et alii* 2006; Caldara and Simone 2005, 2012; Caroli and Caldara 2007; Mastronuzzi *et alii* 2018; Susini *et alii* 2023.

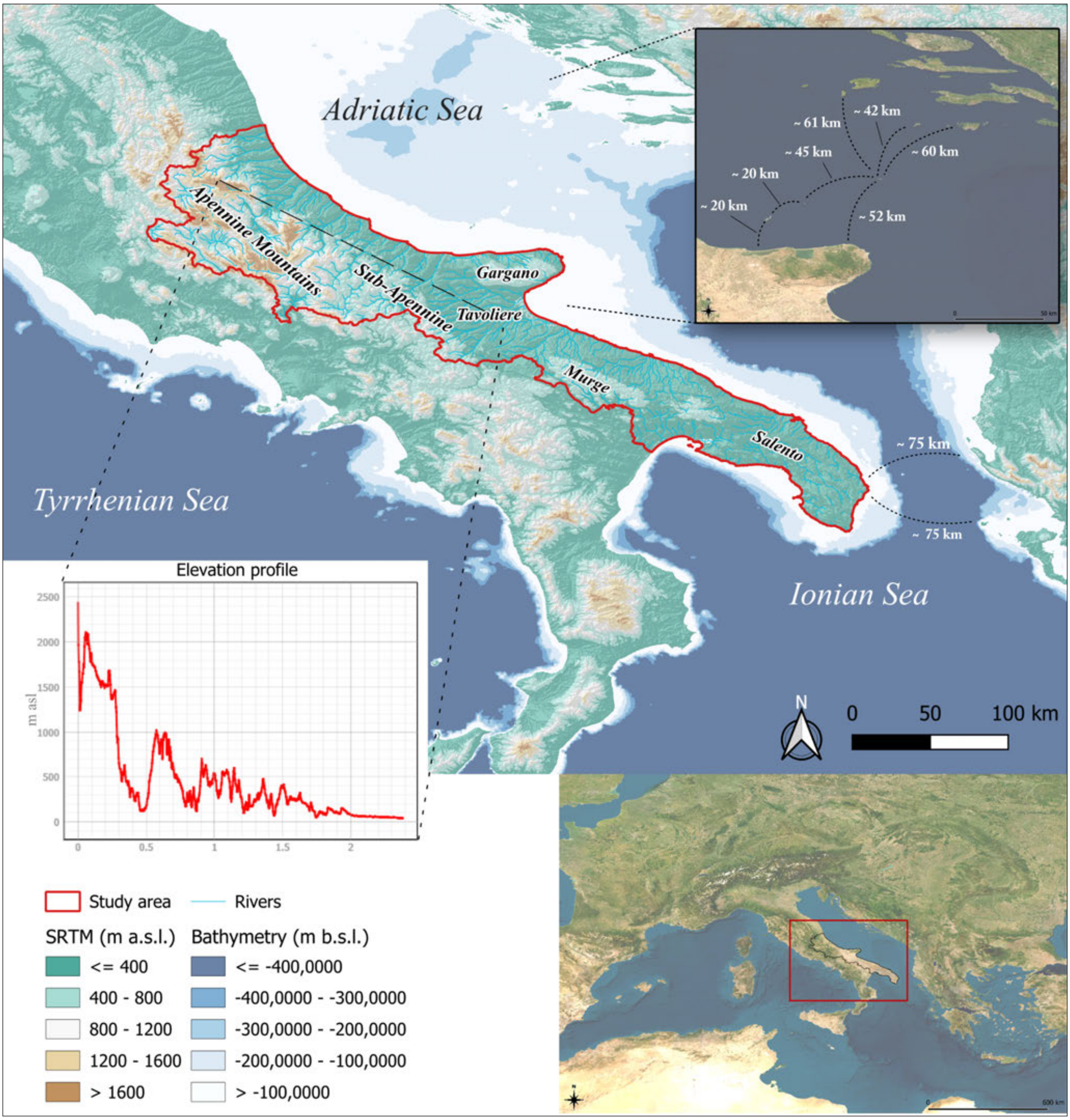

Fig. 1. - The portion of the southern Italian peninsula examined in this study. Shaded relief and hypsometric tint depict the main physiographic units. The study area is outlined in red. The insets show the regional setting and indicative shortest sea-crossing distances across the Adriatic and Ionian.

of Torre Guaceto and Roca Vecchia, both associated with wetlands that underwent significant transformations over time [5].

Significant transformations also took place inland, especially in the Fucino basin, which held one of the peninsula's largest lakes until its final drainage in the 19th century CE [6]. Ringed by Apennine ridges, this lake formed a distinctive ecological niche that attracted human groups from the Palaeolithic through to late prehistory [7]. Because it lacked a permanent outflow, the shoreline advanced and retreated with climatic and tectonic shifts.

Beyond major geomorphological changes, south-eastern Italy experienced continuous anthropogenic impacts linked to agro-pastoral practices. These activities contributed to the gradual retreat of woodlands and the shaping of landforms, including the construction of terraced landscapes – a phenomenon that remains largely unexplored in the southern peninsula.

[5] Iacono *et alii* 2020; Mastronuzzi *et alii* 2018.
[6] Giraudi 1989.
[7] Grifoni Cremonesi *et alii* 2011; Mussi *et alii* 2008; Radi *et alii* 2018.

Fig. 2. - A) Mountainous/hilly landscape of the Abruzzo inland; B) The Fucino basin and surrounding reliefs; C) One of the rocky spurs characterising the inland river valleys of the Molise region (in the picture, the rocky spur of Oratino); D) Southern edge of the Alta Murgia plateau overlooking the Fossa Bradanica plain; E) Aerial photo of the Tavoliere plain, with the Gargano promontory in the background; F) Combined agricultural and grazing land use of the subcoastal wet areas of the northern Tavoliere plain.

	Geomorphological units	*Main landforms & processes*	*Key structural / lithological features*
1	**High Carbonate Apennine Range** (Gran Sasso, Maiella, Matese)	Alpinestyle ridges, glacial cirques, highlevel karst plateaux	Thick MesoCenozoic platform carbonates; stillactive Quaternary uplift & normal faulting
2	**Intramontane Basins** (Fucino, Sulmona, Bojano, Isernia)	Flat or gently undulating lacustrinealluvial plains, fault scarps, coalescing fans	Halfgraben floors infilled by >1 km of PlioQuaternary sediments within active normalfault arrays
3	**SubApennine Flysch Hills** (Frentani & Daunia)	Moderaterelief cuesta ridges, deepseated slides, badlands	Thinskinned flysch nappes (Faeto, Daunia Clays) folded into thrustpropagation anticlines; low rock strength promotes earthflows
4	**Adriatic–Bradanic Foredeep & Coastal Plains** (Tavoliere di Puglia, lower Trigno–Biferno)	Broad marine & fluvial terraces, deltaic plains, subsiding coastal wetlands	Quaternary siliciclastic wedge over foredeep flexure; gentle Holocene subsidence
5	**Foreland Carbonate Bulge** (Gargano promontory, Alta & Premurge plateaux)	Uplifted karst plateaux, doline fields, faultbounded scarps	Rigid Apulia foreland horsts; neotectonic arching of Adria plate margin; relative uplift of 600–1000 m
6	**Salento Foreland Platform** (Serre Salentine)	Subaerial coralreef limestones, stepped marine terraces, shallow karst	Gently tilting Apulian foreland block segmented by horstandgraben fabric; minimal Quaternary uplift; tectonically stable karst erosion surface

Table 1. - Geomorphological units characterising the study area.

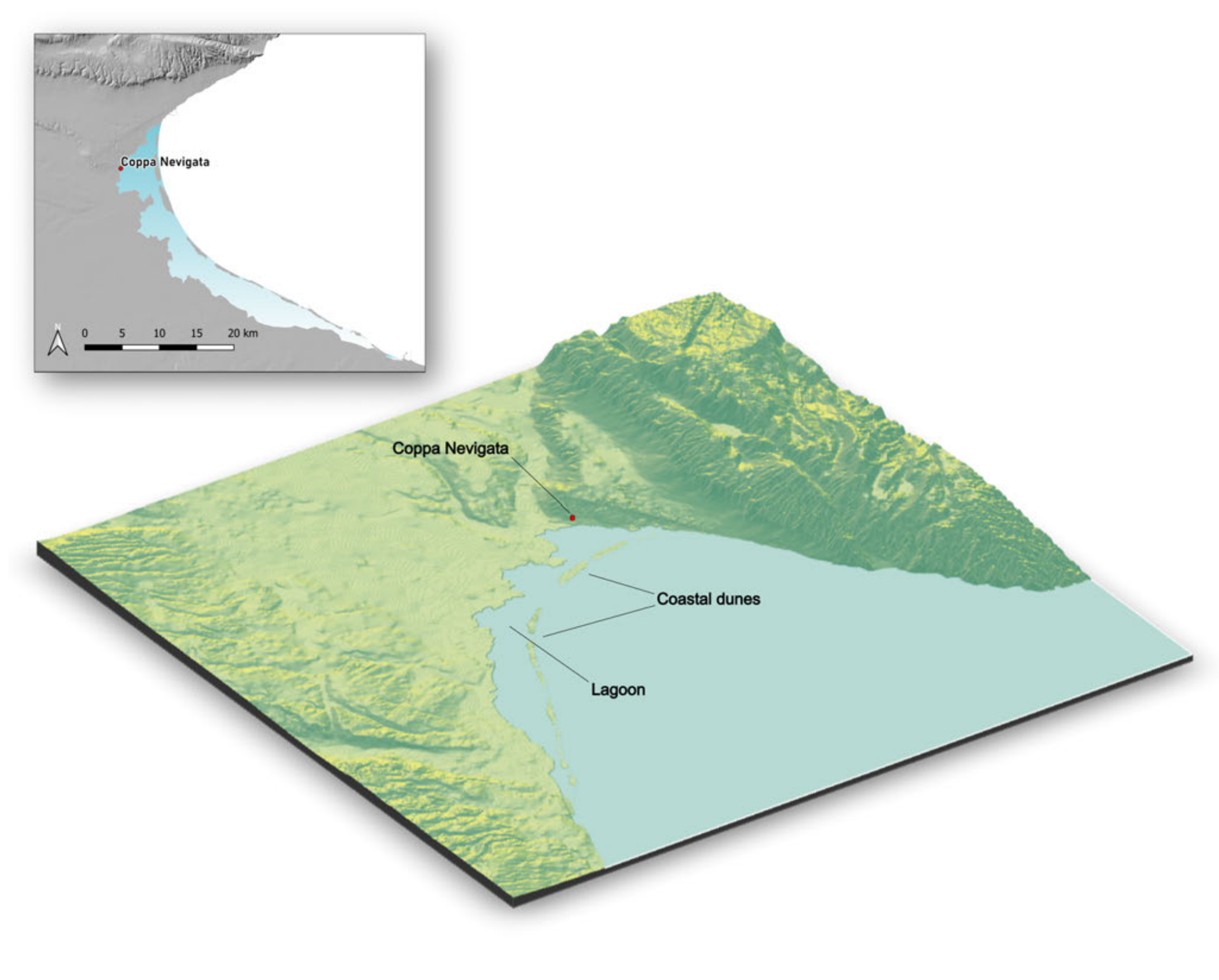

Fig. 3. - Virtual landscape reconstruction of the Salso lagoon and its surrounding territory during the 2nd mill. BCE (based on Susini *et alii* 2023 and Caldara and Simone 2012). The map also indicates the location of Coppa Nevigata, which has yielded significant evidence of both an Early Neolithic and a Bronze Age settlement.

However, evidence from other parts of the central Mediterranean suggests that such practices may have already begun during Late Prehistory [8]. In the last century, the rise of mechanised agriculture, the expansion of urbanisation and industrialisation – intensified by the post-war "economic miracle" – greatly accelerated landscape transformation processes, adding a further layer of cultural stratification linked to the contemporary era. However, this should not lead to an underestimation of the activities that had already profoundly reshaped the landscape in earlier historical periods [9].

2. Environmental background: climate and vegetation

Over the past decades, a growing body of high-resolution of palaeoenvironmental studies has contributed to reconstructing Holocene environmental and climate dynamics in the Central Mediterranean. These studies have employed multiproxy approaches – combining palynological, sedimentological, archaeobotanical and isotopic analyses – to trace long-term vegetation change, hydrological fluctuations, and the interplay between climate variability and human agency [10].

[8] French *et alii* 2020.
[9] Sereni 1976.

[10] Combourieu-Nebout *et alii* 2013; Di Rita *et alii* 2018; Giraudi *et alii* 2011; Goudeau *et alii* 2015; Peyron *et alii* 2017; Sadori *et alii* 2011.

Given the breadth, yet uneven coverage, of the available literature across these territories, the following overview therefore concentrates on the key studies that underpin the environmental framework adopted here.

In the northernmost part of the study area (Abruzzo region), researchers have focused on the Fucino basin, providing information on vegetation, climatic fluctuations, and associated hydrological changes. Sediment cores extracted from the innermost and deepest part of the former lake have enabled the reconstruction of vegetation and climate history from the late Pleistocene through the Holocene. These results, however, must be interpreted with caution: the absence of radiocarbon dates means that the chronology of major shifts has been inferred by comparison with the dated sequence from Valle di Castiglione [11].

Giraudi's studies document mid- and late-Holocene hydrological fluctuations of the Fucino lacustrine system, linked to climatic shifts and contextualised through comparisons with other lake records from the Italian peninsula [12]. More recently, the analysis of tephra layers from deposits located at 1600-2700 m a.s.l. in the central Apennines has provided fresh interesting data on environmental and climatic changes between c. 4.5 and 3.8 cal ka BP. These data shed light on the complexity of this interval and help to define the onset of the Holocene 'Neoglacial' [13] in central Italy shortly after 5 ka [14].

Further south, for the Apulia region diverse and recent studies are available. An important reference is the work of Fiorentino and colleagues, which explores the interplay between settlement dynamics and climate variability in the Tavoliere plain from 6200 to 3700 BCE [15]. Drawing on both published and newly acquired palaeoenvironmental data, the authors combine archaeological evidence with Bayesian modelling of radiocarbon probability curves, multiproxy records from sediment cores, and archaeobotanical analyses from multiple sites. This multidisciplinary approach highlights how phases of settlement expansion and contraction correspond to climatic fluctuations, and how these in turn influenced land use and subsistence strategies.

The Gargano promontory preserves an excellent mid- to late-Holocene pollen record at Lago Battaglia. Caroli and Caldara analysed a 5.50 m sediment core from the former lake, located on the eastern Gargano coast, using pollen and microcharcoal [16]. Six AMS radiocarbon dates on plant macroremains provide a chronology covering about the last 6000 years.

Another extensively investigated wetland in the study area is the Salso-Salpi lagoon, which once stretched south of the Gargano promontory (fig. 3). Over the past decades, multidisciplinary studies have refined reconstructions of its Holocene extent and transformations. In the early 2000s, its long-term evolution was outlined through geological, geomorphological, and archaeological data, supplemented by documentary sources dating from the Roman period [17]. About a decade later, high-resolution environmental records from sediment cores near Coppa Nevigata provided detailed reconstructions of lagoonal and vegetation changes, integrating pollen, mollusc, and foraminifera analyses [18]. More recently, micropalaeontological, palynological, and sedimentological data from the southern sector (Salpi lagoon) have further refined understanding of this ecosystem and prompted a reassessment of earlier models [19].

Expanding the view to the Salento Peninsula, Di Rita and Magri [20] present the first mid- to late-Holocene pollen record from a coastal setting in the easternmost part of Apulia, based on a 4.1 m sediment core from Lago Alimini Piccolo. Dated with five AMS radiocarbon measurements, the ~5500-year sequence integrates pollen and microcharcoal data to reconstruct vegetation change in relation to climate and human impact. The sequence records a forest retreat around 4000 cal BP within the central Mediterranean evergreen belt, interpreted as a natural aridification linked to the north-eastward expansion of the North African high-pressure cell.

[11] Magri and Follieri 1991.

[12] Giraudi 1989, 2007.

[13] The term Neoglacial refers to a series of mid- to late Holocene cold phases. In the central Mediterranean, the Holocene Neoglacial is marked by renewed glacier advances, particularly the regrowth of the Calderone Glacier in the Central Apennines after c. 5 ka. This climatic shift, identified through geomorphological, palaeoecological, and sedimentary records, coincided with broader environmental changes, including increased periglacial activity, altered hydrology, and vegetation shifts at higher altitudes. Stratigraphic markers such as the Agnano Monte Spina and Avellino tephra layers provide a precise chronological framework for recognising its onset in central Italy between c. 4.5 and 3.8 cal ka BP (Zanchetta *et alii* 2012).

[14] Zanchetta *et alii* 2012.

[15] Fiorentino *et alii* 2013.

[16] Caroli and Caldara 2007.

[17] Boenzi *et alii* 2006; Caldara *et alii* 2002.

[18] Caldara and Simone 2012; Di Rita *et alii* 2011.

[19] Susini *et alii* 2023.

[20] Di Rita and Magri 2009.

With the environmental framework established, the next section introduces the chronocultural setting of the Copper (4th - 3rd mill. BCE) and Bronze Ages (2nd mill. BCE).

3. Chronocultural framework of the Copper and Bronze Ages (~4000-1000 cal. BCE)

Defining cultural and chronological aspects across a region as vast as the Southeast Italy for the period under scrutiny is inherently challenging. The traditional framework is based primarily on the stylistic characteristics of *impasto* pottery, but this sequence is only partly supported by radiocarbon dating. As a result, our ability to trace the spatial and temporal development of cultural phenomena – especially in the earlier phases – remains limited.

These frameworks should therefore be approached with an awareness of their internal variability, as reflected in the production of Impasto pottery in domestic contexts within largely autonomous communities, where local practices could diverge significantly. Although these groups maintained direct or indirect contacts at different scales, they often followed their own cultural rules in artefact production. Such intra-community variability could even manifest at the household or kinship level, among individuals residing within the same settlement.

That said, during the different phases of the Copper and Bronze Ages, the study area witnessed shared stylistic traditions [21], indicating an extensive interaction network among communities of the Adriatic side of central-southern Italy, likely based on mediated contacts, as well as aspects witnessing contacts with the Tyrrhenian side of the peninsula.

The scheme presented in fig. 4 summarises the main stylistic traditions of Impasto pottery in the study region. It is important, however, not to interpret these stylistic aspects as homogeneous chrono-geographic units, neatly defined and arranged in strict sequence, since diverse traditions frequently overlapped even at local scale. Rather, the following discussion provides a general cultural and chronological framework for the study area. This framework has been used both as a reference for the chronological attribution of the analysed contexts and as a contribution to the overall consistency of this publication.

Regarding the 4th mill. BCE, one of the earliest stylistic phenomena – characterised by zig-zag incisions within and below the rim of bowls – finds a notable distribution across both the northern and southern parts of the study area. This tradition is referred to as the Macchia a Mare culture in northern Apulia, while further north, for example in the Fucino basin, it is labelled as the Paterno culture [22], or more broadly across southern Italy as Diana-Spatarella [23]. Despite these differing names, these assemblages share remarkably similar stylistic features and reflect a broader decorative model circulating along the Adriatic coast during the earliest phases, between the end of the 5th and the beginning of the 4th mill. BCE. Also within the 4th mill. BC, even if slightly later and in the broader context of southern Italy, Apulia saw the diffusion of stylistic traits associated with the Piano Conte tradition, characterised by grooved decorations and subcutaneous handles [24]. In contrast, in Abruzzo (i.e. Ortucchio and Le Coste [25]), albeit less frequently, elements of the Conelle culture appear during the second half of the mill. [26]. These are marked by bands of impressed dot motifs and are mainly attested along the central Adriatic side of the peninsula. Within this broader stylistic framework, we also find ceramic productions employing various techniques to roughen the surface of the vessels, culminating in scale-like surface decorations, which exhibit a wide distribution both geographically and chronologically, spanning from at least the second half of the 4th mill. BCE into the advanced stages of the 3rd mill. BCE [27].

A long-lasting phenomenon – spanning from the second half of the 4th to the final centuries of the 3rd mill. BCE – encompassing the entire study area while also extending along the Tyrrhenian side, particularly south of the Tiber, is the Laterza culture [28]. It is generally attested in funerary contexts. Its most distinctive features include gourd-shaped vessels with incised decorations – such as bands of segments, filled triangles, or zig-zag motifs – paterae with radial incised patterns on the outer surface, and handles with

[21] On that subject, the recent book by A. Cazzella and G. Recchia provides an extensive and comprehensive synthesis (Cazzella and Recchia 2021).

[22] Pessina 1991.

[23] Pessina and Tine 2008, p. 77.

[24] Bernabò Brea and Cavalier 1980; Pacciarelli 2008.

[25] Radiocarbon dates from Le Coste confirm the Eneolithic occupation of the site during the late 4th to early 3rd millennium BCE (Rome 775: 4535±65 BP, 3240–3110 cal BCE; LTL054A: 4383±60 BP, 3130–2880 cal BCE; LTL056A: 4307±60 BP, 3030–2870 cal BCE) (Angeli *et alii* 2011; Cazzella 2003; Radi 2003).

[26] Cazzella 2003.

[27] Cazzella and Moscoloni 1999.

[28] Carboni 2020a.

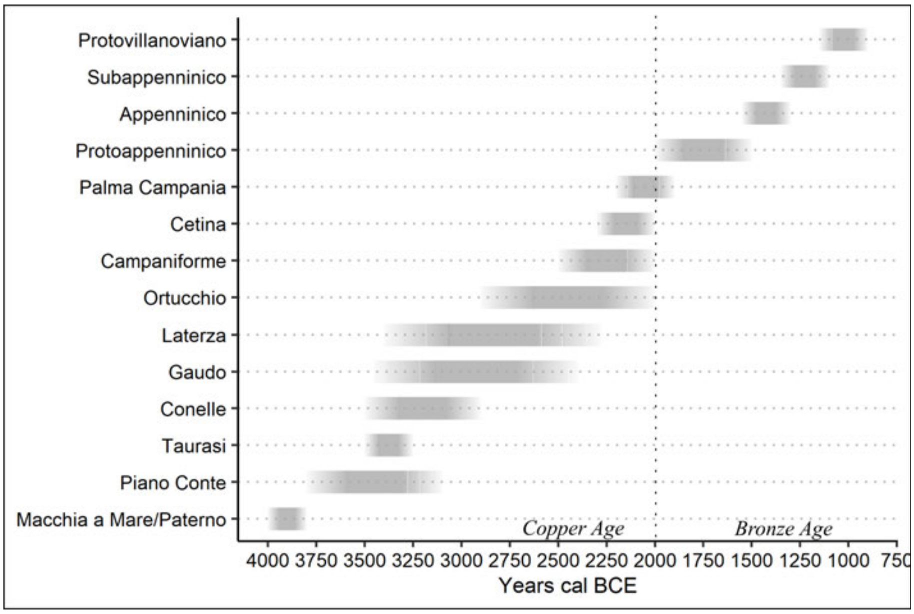

Fig. 4. - Duration of the main impasto pottery traditions in south-east Italy, showing their chronological overlap between the Late Copper Age and the Bronze Age.

summit knobs. In the inland areas of Abruzzo – i.e. in sites of the Fucino basin and "Valle Subequana" interpretable as settlements [29] – ceramics with scale-like decorations are frequently associated with knobbed handles as well as elbow-shape handle, yet this association is generally referable to advanced moments of the Laterza culture (3rd mill. BCE).

Evidence of the Gaudo culture is relatively scarce in the study area. Although its chronology spans a broad arc between the 4th and 3rd millennia BCE – and it is well attested along the Tyrrhenian side of central-southern Italy – it appears only in a handful of funerary contexts in Apulia [30]. For this reason, it does not serve as a basis for classifying the sites analysed in this study.

In contrast, the 3rd mill. BCE saw the emergence of new cultural expressions, including the Ortucchio aspect [31], named after the site of the same name in the Fucino basin. However, this remains a relatively isolated case, as the main area of distribution lies in the southern area of Rome. In inland Abruzzo, this phase is also marked by occasional finds reflecting influence from Bell Beaker traditions (e.g. La Serpentana and Grotta di Beatrice Cenci) [32]. South-eastern Italy also fits within the broader framework of Cetina style diffusion in the central Mediterranean during the late 3rd mill. BCE. A few examples are known from the inland areas of Abruzzo (such as San Callisto – Popoli and Navelli), while more substantial evidence comes from Apulia, particularly from its northern and central areas [33].

Among the earliest Bronze Age evidence in Apulia is the Palma Campania aspect, recorded in the northern and central parts of the region. While this stylistic tradition is most widely attested in the Campania region, recent discoveries in Apulia challenge the assumption of merely sporadic presences in the Adriatic side of the peninsula. Instead, they point to more stable and sustained contacts between communities on either side of the Apennine chain [34].

Partly contemporary with the advanced phase of Palma Campania, the Protoapennine tradition emerged – distinguished by elevated, axe-shaped handles – and saw wide diffusion across central and southern Italy. In the past, the eruption of the Avellino Pumice (ca. 1900 BCE) was considered a cultural watershed separating these two traditions [35]. However, while it remains an important chronological marker, evidence exists of Protoapennine elements predating the eruption, as well as Palma Campania traits persisting after it. Radiocarbon-dated contexts place the beginnings of the Protoapennine already at the start of the 2nd mill. BCE, with continuity at least until the 16th century BCE [36]. Local reworkings are also attested, such as the southern variant known as Cavallino [37].

The 15th and 14th centuries BCE saw the spread of the Apennine tradition, whose hallmark is the incision of geometric motifs on pottery surfaces [38]. Again, local reinterpretations of these reference models are

[29] Cosentino *et alii* 2007; Cosentino and Mieli 2011.

[30] Radina 2015.

[31] Carboni 2020b.

[32] Angeli and Fabbri 2011; Cosentino *et alii* 2001.

[33] Recchia 2022.

[34] Recchia *et alii* 2024b; Soriano and Livadie 2015; Tunzi *et alii* 2012b.

[35] Sulpizio *et alii* 2010a,b.

[36] Calderoni *et alii* 2012.

[37] Cremonesi 1977; Recchia and Ruggini 2009.

[38] This overview excludes Aegean-Mycenaean traditions for editorial reasons, though they played a key role in specialised

frequent, affecting both decorative patterns and vessel features such as handles – as exemplified by the Punta le Terrare aspect [39].

The final centuries of the 2nd mill. BCE are instead characterised by the spread of the Subapennine stylistic tradition, which features elaborated raised elements above the handles, alongside a decline in surface decoration. This is followed by the emergence of new stylistic traits, characterising the Final Bronze Age, marked by a renewed emphasis on complex surface decoration made with grooved motifs, spanning the 11th and early 10th centuries BCE [40].

4. Social, demographic and political frameworks in southeastern Italy

This section offers a general overview of the social context and settlement evidence, providing the framework for interpreting the data discussed in the following chapters.

Broadly speaking, communities in south-eastern Italy between the 4th and 2nd millennia BCE were characterised by limited demographic scale. Estimates based on archaeological evidence from funerary and settlement contexts, combined with ethnographic comparisons, suggest groups ranging from a few dozen inhabitants in scattered hamlets to several hundred in the long-lived fortified coastal settlements that emerged during the Bronze Age [41]. In terms of social organisation, the archaeological evidence does not indicate stable forms of stratification understood as institutionalised political power, and there is no evidence for the presence of established elites.

For the Copper Age, there may have been instances of the temporary rise of prominent individuals [42], for reasons that could have varied from military to political abilities (noting that in prehistoric contexts such roles were likely intertwined, and not compartmentalised into distinct spheres as in modern interpretations). By contrast, indirect indications of possible emerging elites appear from the mid-2nd millennium BCE and become more evident in the later phases of the Bronze Age.

A look at the settlement models documented in the study area. For the Copper Age, as is well known, the data are not particularly abundant [43]. Although the scarcity of archaeological evidence is not, in itself, a particularly reliable indicator, it may nevertheless – pending contrary proof – suggest settlement strategies that did not involve the prolonged occupation of the same physical location. But this does not necessarily imply a shift towards more mobile, pastoral-based societal models, nor a crisis in the notion of a stable settlement – a model, moreover, contradicted by recent isotopic analysis data [44] as well as by the significant amount of settlement evidence from the area south of Rome [45].

Conversely, this may point to the absence of a long-term inherited idea of delimited co-residence space of the community [46]. Communities in this period could be understood as dispersed networks bound by kinship, with internal groups of individuals that were not static entities but active participants in fields of action – social, political, economic, and symbolic [47]. Each kin group's position and role within this network was shaped through ongoing relationships – both with other groups and with the material environment – giving rise to a form of relational agency that influenced how space was used, shared, or reconfigured. Settlement space, in this perspective, can be understood as a spatial configuration emerging from kin-based relational ties, whose arrangement may have varied over time as groups formed or dissolved, expanded or fragmented, or as resource requirements changed [48]. Such transformations made settlements more dynamic in both social and spatial terms, and the apparent scarcity of settlement evidence in the archaeological record may reflect not an absence of activity, but the inherent difficulty of detecting the material traces of these dynamics.

The settlement at Valle Cancelli (Volturino, FG) (fig. 5A), dating to the early 4th mill. BCE, was located on a ridge with a natural defensive position and consisted of at least five elongated, east – west-oriented huts with apsidal ends to the west and entrances to the east [49]. These structures measure between c. 14.5 m and 20.5 m in length and ca. 5 m in width; in some

craft development and in anchoring absolute chronology (Bettelli 2002).

[39] Radina 1998; Recchia and Ruggini 2009.

[40] Harari and Pearce 2000.

[41] Guglielmino 2014; Recchia and Baroni 2011; Recchia and Cazzella 2019, p. 93.

[42] Anzidei *et alii* 2020, p. 410; Salerno 1993.

[43] Cazzella 2021.

[44] Bernardini *et alii* 2021; De Angelis *et alii* 2021.

[45] Anzidei and Carboni 2020.

[46] As could be suggested by the *Villaggio Trincerato* model.

[47] Robb 2010.

[48] Goody 1958.

[49] Tunzi *et alii* 2012a.

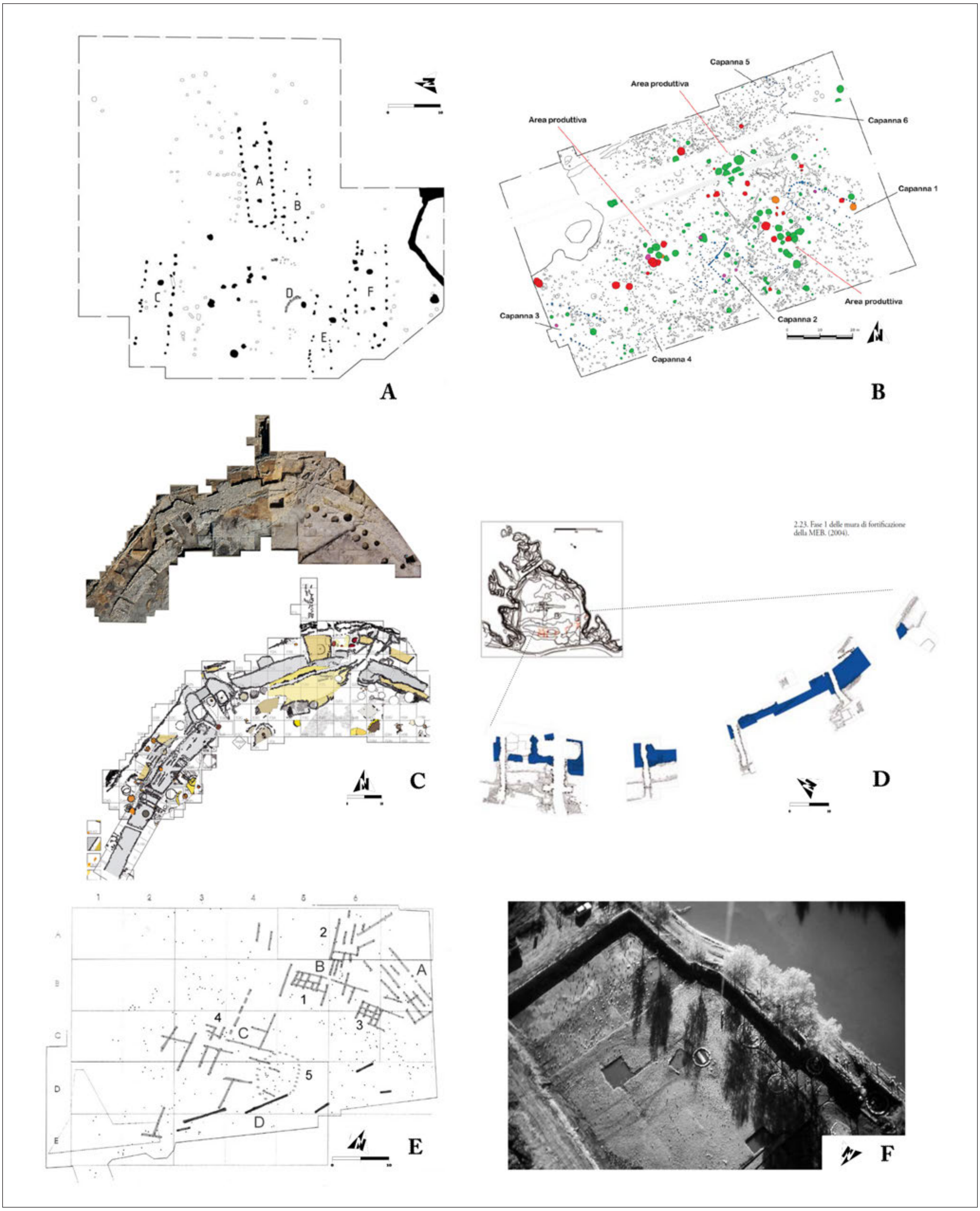

Fig. 5. - A) Volturino – Valle Cancelli: plan of main archaeological features, with letters indicating huts (re-elaborated after Tunzi *et alii* 2012a); B) Posta Rivolta: final excavation plan with numbered hut-related features (re-elaborated after Tunzi *et alii* 2012b); C) Coppa Nevigata: aerial view and multi-phase plan of principal structures (re-elaborated after Cazzella *et alii* 2012); D) Roca: plan of Middle Bronze Age fortification wall (re-elaborated after Scarano 2012); E) Celano Paludi: final plan showing interpreted dwelling structures from preserved wooden post alignments (re-elaborated after D'Ercole and Menozzi 2016); F) Celano Paludi: aerial view of excavation area (re-elaborated after D'Ercole and Menozzi 2016).

cases, evidence suggests internal partitions and associated external features [50]. It is difficult to determine whether structures of such size were occupied by a nuclear or an extended family, as size alone is a risky criterion [51]; the number of inhabitants should instead be inferred from associated features and patterns of internal space use. What is more significant, however, is the construction effort, which likely required the collaboration of several individuals beyond the nuclear family (perhaps bound together by wider kinship ties?). Moreover, it is not straightforward to determine whether they were all in use contemporaneously; we cannot exclude the possibility that they represent episodes of rebuilding over a short period [52].

This model, characterised by small hamlets [53], had a long continuity over time, persisting into the Bronze Age [54]. However, a significant transformation began during the first half of the 2nd mill. BCE with the emergence of long-lasting artificially fortified settlements in southern Italy and the adjacent islands, as part of a broader phenomenon that encompassed much of the Central Mediterranean and reflected the wider militarisation of society during the Bronze Age [55]. In the study area, the phenomenon primarily affected the Adriatic and Ionian coastal and subcoastal zones, with the Gargano promontory – also involved in the process – marking its northern limit (fig. 6) [56]. These fortified sites were distinguished by massive and complex defensive systems built in dry stone (fig. 5C-D), designed to protect communities from terrestrial assaults. Their architectural model was likely influenced by that of Aegean centres dating to the early 2nd mill. BCE (MH II–III), such as Kolonna (Aegina), Ayia Irini (Kea), and Palamari (Skyros) [57].

In this process, the expansion of long-range maritime exchanges connecting diverse societies of the Central Mediterranean from the late 3rd mill. BCE onward played a primary role. In fact, fortified coastal communities were actively engaged in this network, not merely as hubs for the exchange of goods, but also as centres of specialised craft production [58]. Coppa Nevigata (Northern Apulia) and Roca Vecchia (Southern Apulia) (fig. 5C-D) represent probably the most informative case studies, since systematic and extensive investigations carried out over the last decades [59]. Their demographic composition has been estimated at several hundred people [60].

A crucial aspect is their long-term occupation of the same physical location, often lasting for centuries. Hence, these were larger communities compared to Copper age ones and within a well-defined settlement space, where kinship ties likely persisted as the basis for defining internal groups and for physically shaping social spaces [61]. Yet, such groups also cooperated in the construction of large structures (e.g. defensive walls), as well as in the maintenance and reorganisation of communal areas, although how these internal diversifications influenced the management of exchange and craft activities – particularly specialised ones – as well as the management of primary resources, especially agropastoral activities remain open questions.

Beyond coastal zones, starting from the mid-2nd mill. BCE, fortified centres or settlement located in naturally defend positions, controlling natural routes of movement, started to emerge also in the inland [62], stressing the increasing involvement of inland communities in exchange networks, while at the same time highlighting growing tensions at the local scale.

Other settlement models can also be cited – for example, the pile-dwelling sites along the shores of the Fucino [63] basin (fig. 5E-F). These structures allowed

[50] Geophysical prospection revealed additional huts and a probable north–south fence or palisade, as interpreted by the authors.

[51] Bourdieu 1977; Morgan 1881.

[52] As witnessed by other contexts, such as Gricignano di Aversa (Fugazzola Delpino *et alii* 2003).

[53] See "traditional" settlement pattern in Cazzella and Recchia (2018).

[54] For example, the settlement of Posta Rivolta, located in the inland/lowland of northern Apulia (fig. 5B, cfr. Tunzi *et alii* 2012b).

[55] Cazzella and Recchia 2013.

[56] Data on the emergence of fortified settlements in the Adriatic corridor were collected by the author as part of a broader investigation into fortified sites along the Adriatic Sea, carried out during two previous projects at the Eurasia Department of the German Archaeological Institute in Berlin (funded by DAAD) and at Sapienza University.

[57] Facorellis *et alii* 2015; Gauss 2019; Gorogianni and Fitzsimons 2017; Recchia and Cazzella 2019; Romanou 2015; Wild *et alii* 2010.

[58] Recchia and Minniti 2018.

[59] Cazzella *et alii* 2012; Iacono *et alii* 2020; Scarano 2012.

[60] These estimations were obtained by combining internal area measurements with ethnographic demographic models (Kramer 1982), for example, the population of Coppa Nevigata has been estimated at around 300 individuals (Recchia and Cazzella 2019).

[61] The importance of kinship ties in defining internal groups within the community is also indicated by evidence from funerary contexts, an aspect for which reference should be made to the specialised literature proposing different interpretations (Bettelli and Vanzetti 2003; Recchia 1999).

[62] Copat and Danesi 2015; Recchia *et alii* 2024b; Venturo 2010.

[63] D'Ercole 1991; D'Ercole and Menozzi 2016.

Fig. 6. - Spatial distribution of Bronze Age fortified (in red) or suspected fortified (in grey) settlements in Apulia, according to their position - coastal (circles), subcoastal (triangles) and inland (diamonds). Case studies located along the seashore or just in its proximity have been categorised as coastal settlements, while those within 2 walking-hours hours from it have been classified as subcoastal; sites over 2 walking-hours fall into the category of inland settlements (classification has been performed by the use of the R package *Movecost* (Alberti 2019).

communities to adapt to oscillations in lake levels, both seasonal and annual, and to the surrounding marshland, while also serving a defensive function by isolating the settlement from the mainland.

A further interesting case study is the model of settlements established at the base of rocky spurs that dominate the Molise valleys. These spurs stand out as highly visible landmarks in the landscape, offering natural points of reference and control. The best-documented example is Oratino-La Rocca [64], located at the foot of a prominent rocky outcrop along the Biferno

[64] Copat 2022.

Valley, in the inland hilly zone of Molise (fig. 2C). For a long time this was considered an isolated case, but the Molise Survey Project has recently identified further examples of such occupation, beginning in the first half of the 2^{nd} mill. BCE. Taken together, these sites suggest that the use of rocky spurs as focal settlement locations constituted a distinctive pattern in this part of the peninsula [65].

[65] Cazzella *et alii* 2019, 2020.

To conclude, an important aspect of the way communities inhabited the landscape concerns their political organisation. The available evidence does not point to a centre-periphery system or to dominant sites exerting military control over dependent satellites. Instead, the picture is one of local variability, where alliances or inter-community arrangements may have existed but without crystallising into stable territorial hierarchies. This flexible political landscape provides the backdrop for the settlement dynamics and spatial models examined in the following chapters.

3.
Materials and methods

This chapter presents the archaeological and economic data collected, alongside the environmental and paleoclimatic variables incorporated into the analyses. Since MaxEnt modelling is central to this research but remains relatively underused in archaeology – particularly in studies of late prehistory – a dedicated section outlines its theoretical foundations and its practical application within this study.

The project workflow is summarised in fig. 1. Data were analysed through integrated geocomputational approaches [1] and inductive modelling, with MaxEnt complemented by a range of techniques that combine statistical methods (e.g. Principal Component Analysis, PCA) and geospatial procedures (e.g. Point Pattern Analysis, PPA) widely employed in archaeology. The details of these analytical steps are presented in Chapter 4, where each method is introduced in direct connection with the interpretation of results, thereby avoiding unnecessary fragmentation.

[1] Lovelace *et alii* 2019, p. 2.

1. Archaeological and economic datasets

1.1. *Overview of the collected sites dataset*

The spatial dataset analysed in this chapter is based on an extensive review of published archaeological

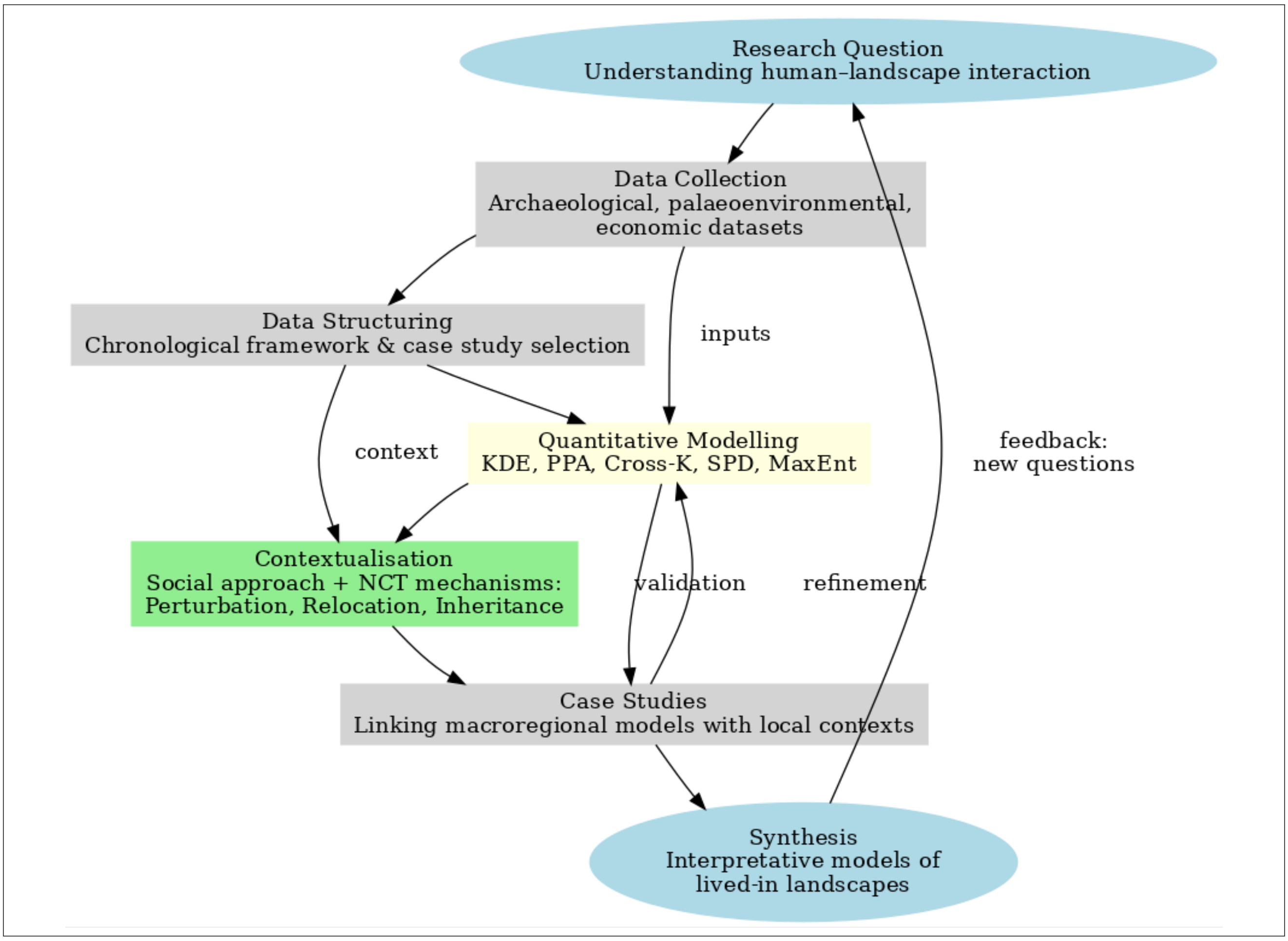

Fig. 1. - Workflow of the analytical approach adopted in the ModLand project. The diagram illustrates the main steps, from the formulation of research questions to the synthesis of interpretative models of lived-in landscapes, highlighting the iterative connections between data, modelling, contextualisation, and case studies.

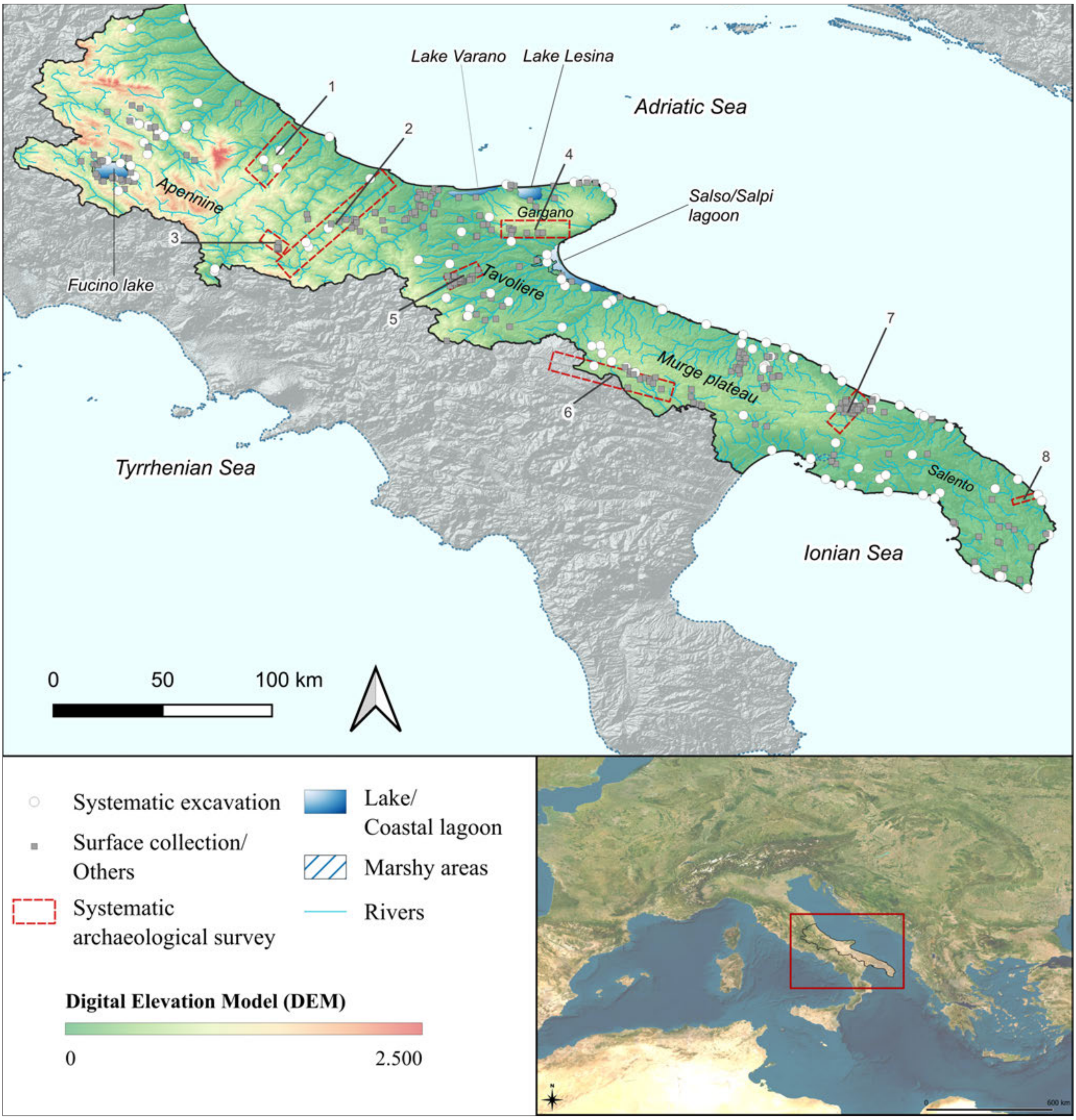

Fig. 2. - Distribution of the analysed case studies. Sites are mapped over shaded relief with major physiographic units indicated. In addition to the present-day hydrography, the map also reconstructs palaeo-water bodies that existed during the period under consideration, notably Lake Fucino in the central Apennines and Lake Salso/Salpi on the northern Apulian coast.

contexts, combining data from the scholarly literature with information derived from recently available web-based datasets (e.g. cartapulia.it). This corpus also includes a number of case studies that have been directly investigated within previous and ongoing research projects.

The dataset consists of 370 case studies dating back to the Copper (4th and 3rd millennia BCE) and Bronze Ages (2nd mill. BCE) [2] (fig. 2). It includes excavated open-air sites, which refer to settlements and/or related functional areas that may indicate human activity, as well as surface collections.

Data acquired for each case study include location, chrono-cultural information (e.g., cultural characterization such as Palma Campania, Protoap-

[2] The chronological range of the collected case studies extends beyond the specific period addressed by the project. This choice is based on two factors: (i) various chrono-cultural complexes, primarily defined by pottery styles, span both the 4th and 3rd millennia BCE, making precise differentiation impossible; (ii) adopting a broader chronological perspective enables a more effective analysis and contextualization of communities-landscape interactions, considering that major transformations in settlement patterns during the Copper Age began in the 5th to early 4th millennium BCE.

penninico, Appenninico, etc.), the availability of radiocarbon dates, type of investigation, references, site characterization (e.g., fortified settlement, open-air settlement, processing area, etc.), and economic data, such as the presence of studies on faunal or vegetal remains.

This broad-brush approach inevitably involves data of highly variable quality, ranging from extensively investigated sites to non-systematic surface collections. To address this, data entry categories were designed as broad containers, enabling the cumulative processing of dataset components of different quality, while still preserving key discriminator features. As a result, the analytical categories reflect a level of abstraction appropriate to the scale and aims of the analysis.

Caves and rock shelters were excluded from the dataset, as their functions varied markedly over time, ranging from burial and cultic contexts to seasonal refuges or activity areas, and therefore do not provide a consistent basis for examining long-term settlement dynamics. While it is generally acknowledged that caves were only rarely used as permanent habitation sites3, except in specific cases not represented within the study area, this analysis is concerned with different processes. The analytical framework adopted here focuses on transformations and continuities in settlement patterns at a broad spatial scale, privileging contexts that can be compared in terms of stable occupation and their role in shaping cultural landscapes. Including caves and rock shelters would have introduced a degree of functional heterogeneity that, while relevant to other research questions, lies beyond the scope of the present study.

Surface collections were included on the basis of published data, where in most cases the number of sherds or their density is not specified. Any limitations based on a minimum number of fragments or artifacts have been deliberately avoided to preserve the dataset's comprehensiveness. Instead, the significance of each find was assessed individually, taking into account its specific context. This qualitative approach makes it possible to examine human interactions with places in the landscape without introducing arbitrary restrictions, while at the same time acknowledging a certain degree of uncertainty.

To achieve the dissemination and communication aims of the project, the spatial dataset is available through the open MODLAND Webmap - available at this link (https://enricolucci.github.io/MODLANDwebmap/) or by framing the QR code (fig. 3). Each site is accompanied by a table reporting key information, including its name, chronology, and references [3].

Fig. 3. - The QR code links to the webmap associated with the ModLand project.

The majority of the analysed contexts are located in the Apulia region, one of the largest regions in southern Italy and among the most archaeologically investigated areas of the Central Mediterranean. This extensive research is facilitated by its open landscape, which allows for easier identification of archaeological remains, and by its environmental characteristics, such as soil composition and landforms, which supported diverse human activities in Late Prehistory.

However, the map shows an irregular cluster organization, with major concentrations in some areas (fig. 4). The apparent gaps in site distribution within these regions should be interpreted with caution. These blank areas likely do not indicate an actual absence of human occupation but rather result from research biases due to the lack of systematic surveys, as well as environmental factors such as dense vegetation and complex geomorphology, which may hide archaeological evidence.

On that subject, Table 1 presents the main systematic survey projects reporting data about Copper and Bronze Ages carried out in the study area. High-density clusters of evidence have been documented along the Celone valley in the Tavoliere plain, as well as in the Itria valley, which includes portions of the Murge upland and the adjacent coastal plain. Additional data have been obtained for the internal regions of the province of Bari in the Apulia region [4], or the Fucino basin, the Navelli plain, and the Vibrata valley in the Abruzzo region [5] by Superintendencies and freelance researchers. Local groups such as Archeoclub, despite employing non-methodological systematic

[3] References for sites in the web map can be accessed via the link provided on the Webmap page and are not listed at the end of this book.

[4] Radina 1989; Tunzi 1987.

[5] D'Ercole 1996a, b; Ialongo 2007.

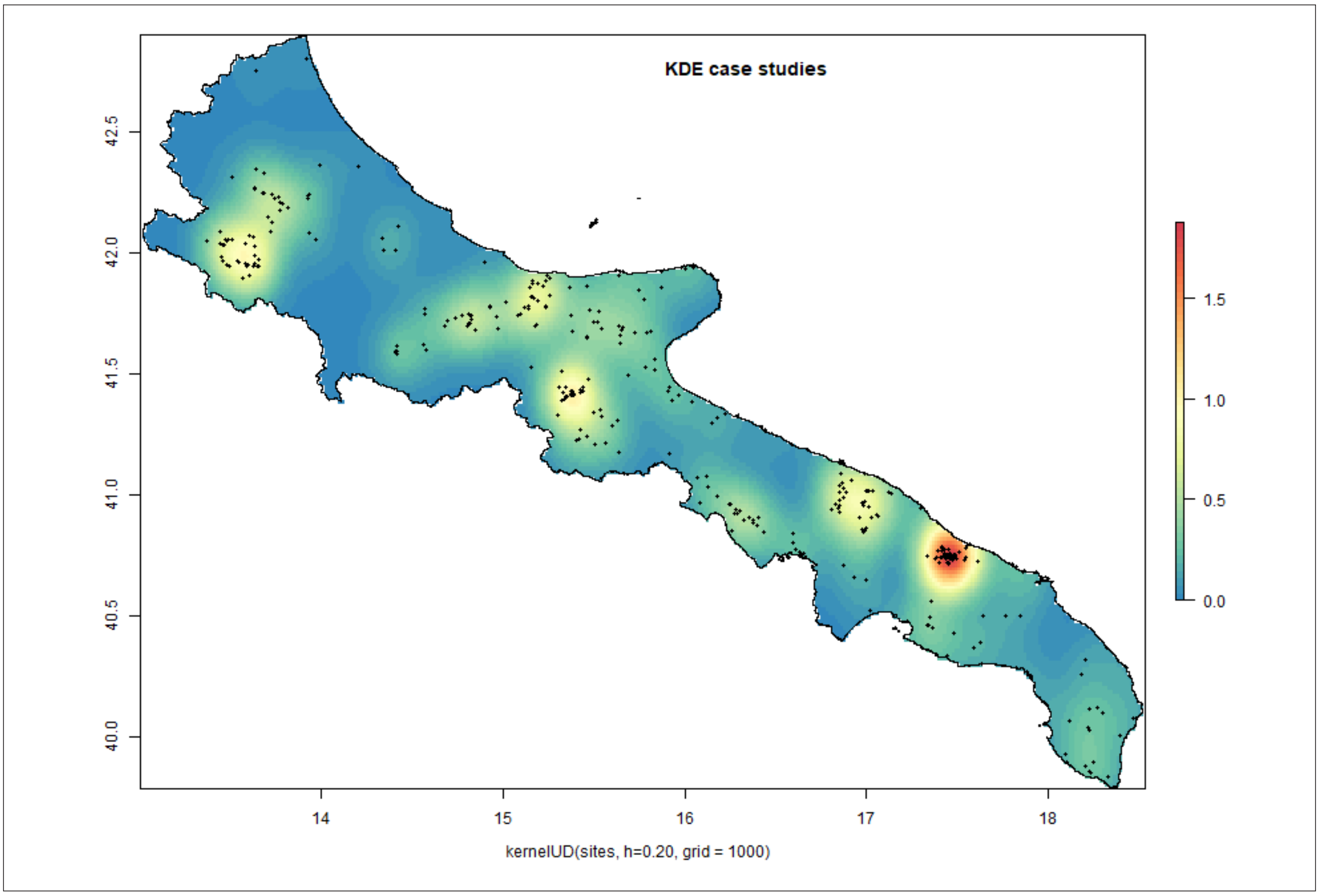

Fig. 4. - Kernel density estimation of the analysed case studies, showing the uneven distribution of contexts across the study area.

Id n.	Project name	Main references
1	Sangro valley Project	I
2	The Biferno Valley Project	II
3	Molise Survey Project	III
4	Gargano Project	IV
5	Progetto Valle del Celone	V
6	Ancient Roads between Venosa and Gravina	VI
7	Ricognizioni archeologiche sull'Altopiano delle Murge	VII
8	Roca Archaeological Survey	VIII

Table 1. - Major systematic survey projects carried out in the study area reporting data about Copper and Bronze Ages.

[I] Lloyd *et alii* 1997.
[II] Barker 1995.
[III] Cazzella *et alii* 2019, 2018.
[IV] Monaco 2016.
[V] Volpe *et alii* 2004.
[VI] Vinson 1972.
[VII] Burgers and Recchia 2009.
[VIII] Iacono *et alii* 2020.

approaches, have also contributed to expanding the available archaeological record. The extensive work undertaken on the Fortore river [6], which divides the Apulia and Molise regions is a notable example.

1.2. *Economic data*

Despite the large number of case studies in the spatial dataset, only a small proportion provides studies on faunal and botanical remains. Moreover, the quality of these data varies considerably: some contexts are supported by systematic analyses yielding detailed qualitative and quantitative information, while others are mentioned only briefly in preliminary reports.

Table 2 synthesises data on the main domestic and wild resources available per site, both plant and animal species, organised according to chronology. In contrast to the approach taken for site distribution, and given the scarcity of available evidence, the economic dataset also incorporates information from selected caves. In this case, caves are not treated as indicators of settlement dynamics, but as sources of information on resource exploitation, allowing the analytical framework to be expanded beyond the relatively small number of open-air contexts with relevant data.

The BRAIN project (Botanical Records of Archaeobotany Italian Network) [7], a comprehensive online

[6] Gravina 1982.

[7] Website: https://brainplants.successoterra.net/

Main information					**Botanical record**			**Faunal record**		
region	**ID**	**Name**	**Chronology**	**Main documented activities**	**Main domestic**	**Main wild**	**Tree fruits**	**Main domestic**	**Main wild**	**References**
Abruzzo		Grotta dei Piccioni	Copper Age	Breeding;				*Sus domesticus*; *Ovis/Capra*; *Bos*;		I
Abruzzo		Grotta Sant'Angelo	ECA-LCA	Breeding; Hunting;				*Ovis/Capra*; *Bos*;	*Capreolus Sus scrofa fer.*	II
Abruzzo	37	Le Coste	ECA-LCA	Harvesting; Breeding; Hunting; Fishing;			*Quercus robur*;	*Ovis/Capra*; *Sus domesticus*; *Bos*;	*Cervus*; *Aves*; *Testudo*; *Pisces*;	III
Abruzzo	29	Ortucchio	Copper Age	Breeding; Hunting;				*Ovis/Capra*; *Sus domesticus*; *Bos*;	*Cervus*; *Sus scrofa fer*	IV
Puglia	320	Rosa Marina	ECA	Breeding; Hunting;				*Ovis/Capra*; *Bos*;	*Cervus*;	V
Puglia	99	Valle Cancelli	ECA	Breeding; Hunting;				*Bos*; *Ovis/Capra*; *Sus domesticus*;	*Cervus*; *Lepus* sp.;	VI

→

[I] Cremonesi 1976.
[II] Iaconis and Boschian 2007.
[III] Castiglioni and Rottoli 2003; Radi 2003.
[IV] Wilkens 1991.
[V] Coppola 1983.
[VI] Tunzi *et alii* 2012a.

Puglia	194	Carluva	EBA	Wood procurement; Agriculture;	*Triticum naked*	*Fraxinus*; *Quercus robur*; *Prunoideae*;				VII
Puglia	181	Coppa Nevigata	EBA	Wood procurement; Agriculture; Breeding; Hunting; Fishing;	*Hordeum*; *Triticum hulled*; *Triticum naked*; *Pulses*;	*Acer/ Fraxinus*; *Cistus*; *Fagus*; *Olea europaea*; *Olea/ Pistacia*; *Ostrya/ Carpinus*; *Populus/ Salix*; *Pistacia terebinthus*; *Pistacia lentiscus*; *Quercus ilex*; *Quercus robur*; *Vitis vinifera*; *Pinus*;		*Ovis/Capra*; *Sus domesticus*; *Bos*;	*Cervus*; *Capreolus*; *Sus scrofa fer.*; *Aves*; *Lepus* sp.; *Pisces*; *Mollusca*;	VIII
Puglia	253	Cozzo Marziotta	EBA	Breeding;				*Ovis/Capra*; *Bos*; *Sus domesticus*;	*Cervus*;	IX
Puglia	276	Egnazia	EBA	Breeding; Hunting;				*Sus domesticus*; *Bos*; *Ovis/Capra*;	*Sus scrofa fer.*; *Cervus*;	X
Puglia	221	Giovinazzo San Salvatore	EBA	Wood procurement; Hunting; Breeding;		*Cistus* sp.; *Corylus/ Alnus*; *Euonymus* sp.; *Olea europaea*; *Fraxinus*; *Pistacia lentiscus*; *Prunoideae*; *Rhamnus/ Phillyrea*; *Quercus ilex*; *Quercus robur*;		*Sus domesticus*; *Bos*; *Ovis/Capra*;	*Sus scrofa fer.*; *Canis lupus*; *Cervus*; *Capreolus*;	XI
Abruzzo		Grotta Sant'Angelo	EBA-MBA	Breeding Hunting				*Ovis/Capra*; *Bos*;	*Cervus*; *Capreolus*; *Lepus*; *Sus scrofa fer.*;	XII
Puglia	191	Le Chianche	EBA	Wood Procurement		*Prunoideae*;				XIII

→

[VII] Primavera *et alii* 2017; Radina *et alii* 2008.
[VIII] Fiorentino and D'Oronzo 2012; Primavera *et alii* 2017; Siracusano 2012.
[IX] Fedele 1979.
[X] Wilkens 1998.
[XI] De Grossi Mazzorin 2010; Primavera *et alii* 2017; Wilkens 1998.
[XII] De Grossi Mazzorin and Minniti 2003; Iaconis and Boschian 2007.
[XIII] Primavera *et alii* 2017.

Puglia	193	Masseria Caterina	EBA	Agriculture; Wood Procurement	*Pulses*; *Hordeum*;	*Fraxinus*; *Ficus*; *Ostrya/ Carpinus*; *Prunoideae*; *Quercus* sp.; *Quercus ilex*; *Quercus robur*; *Rhamnus/ Phillyrea*;		*Sus domesticus*; *Bos*; *Ovis/Capra*;		[XIV]
Puglia	264	Monopoli - Centro storico	EBA	Wood Procurement	*Pulses*;	*Corylus/ Alnus*; *Olea europaea*; *Pistacia lentiscus*; *Quercus robur*; *Quercus ilex*; *Rosaceae/ Maloideae*;				[XV]
Puglia	332	Muro Maurizio	EBA	Breeding; Hunting				*Bos*; *Sus domesticus*; *Ovis/Capra*;	*Cervus*; *Capreolus*;	[XVI]
Puglia	158	Posta Rivolta	EBA	Agriculture	*Triticum* sp.; *Triticum naked*; *Hordeum*;	*Quercus ilex*; *Quercus* sp.; *Quercus robur*; *Olea europaea*; *Prunoideae*; *Myrtus communis*; *Erica*; *Maloideae*;				[XVII]
Puglia	262	San Domenico	EBA	Wood Procurement; Agriculture	*Triticum hulled*; *Hordeum*;	*Olea europaea*; *Prunoideae*; *Quercus robur*; *Quercus ilex*; *Quercus* sp.;				[XVIII]
Puglia	331	Scogli di Apani	EBA	Harvesting; Wood Procurement	*Pulses*;	*Erica*; *Olea europaea*; *Ostrya/ Carpinus*; *Quercus robur*; *Quercus ilex*;	*Ficus carica*;			[XIX]
Abruzzo	56	Torre dè Passeri	EBA	Breeding				*Bos*; *Ovis/Capra*; *Sus domesticus*;		[XX]

→

[XIV] Minniti 2021; Primavera *et alii* 2017.
[XV] Primavera *et alii* 2017.
[XVI] Cremonesi 1977.
[XVII] Tunzi *et alii* 2018.
[XVIII] Primavera *et alii* 2017.
[XIX] *Ibidem*.
[XX] De Grossi Mazzorin and Minniti 2003.

Abruzzo	21	Cerchio - La Ripa	MBA	Breeding; Hunting				*Equus caballus*; *Bos*; *Sus domesticus*; *Ovis/Capra*;	*Cervus*; *Sus scrofa fer.*; *Aves*;	[XXI]
Abruzzo	19	Collelongo - Fond'Jò	MBA-LBA	Breeding; Hunting				*Ovis/Capra*; *Sus domesticus*; *Bos*; *Equus caballus*; *Equus asinus*;	*Aves*;	[XXII]
Puglia	181	Coppa Nevigata	LBA	Agriculture; Wood Procurement; Fishing; Breeding; Hunting	*Hordeum*; *Triticum hulled*; *Triticum naked*; *cfr. Avena*; *cfr. Secale*; *Pulses*;	*Acer/Fraxinus*; *Fagus*; *Euphorbia*; *Ostrya/Carpinus*; *Prunoideae*; *Quercus robur*; *Quercus ilex*; *Pinus*; *Olea europaea*; *Pistacia cfr. terebinthus*; *Rhamnus/Phillyrea*; *Juniperus*; *Cistus* sp.;		*Bos*; *Equus caballus*; *Ovis/Capra*; *Sus domesticus*;	*Cervus*; *Capreolus*; *Sus scrofa fer.*; *Lepus* sp.; *Aves*; *Testudo*; *Pisces*; *Mollusca*;	[XXIII]
Puglia	181	Coppa Nevigata	MBA	Breeding; Hunting; Fishing				*Ovis/Capra*; *Sus domesticus*; *Bos*; *Equus caballus*;	*Cervus*; *Capreolus*; *Sus scrofa fer.*; *Vulpes*; *Testudo*; *Aves*; *Pisces*; *Mollusca*;	[XXIV]
Puglia	221	Giovinazzo San Salvatore	MBA	Hunting; Breeding				*Sus domesticus*; *Bos*; *Ovis/Capra*;	*Sus scrofa fer.*; *Cervus*; *Capreolus*;	[XXV]
Puglia	276	Egnazia	MBA	Breeding; Hunting				*Sus domesticus*; *Bos*; *Ovis/Capra*;	*Sus scrofa fer.*; *Cervus*;	[XXVI]
Molise	73	Fonte Maggio	MBA	Agriculture; Harvesting; Breeding	*Triticum hulled*; *Triticum naked*; *Proso millet*; *Hordeum*; *Pulses*;		*Corylus avellana*; *Vitis silvestris*;	*Ovis/Capra*; *Sus domesticus*; *Bos*;	*Aves*; *Cervus*; *Capreolus*;	[XXVII]

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[XXI] *Ibidem*.
[XXII] *Ibidem*; Grifoni Cremonesi 1973.
[XXIII] Fiorentino and D'Oronzo 2012; Minniti *et alii* 2022; Recchia *et alii* 2021; Siracusano 2012.
[XXIV] Primavera *et alii* 2017; Siracusano 2012.
[XXV] Wilkens 1998.
[XXVI] *Ibidem*.
[XXVII] Barker 1995, p. 132.

Abruzzo		Grotta a Male	MBA	Breeding				*Bos*; *Ovis/Capra*;		XXVIII
Abruzzo		Grotta a Male	LBA1	Breeding				*Bos*; *Ovis/Capra*; *Sus domesticus*;		XXIX
Abruzzo		Grotta a Male	LBA2	Breeding				*Bos*; *Ovis/Capra*; *Sus domesticus*;		XXX
Abruzzo		Grotta di Beatrice Cenci	MBA	Breeding				*Sus domesticus*; *Ovis/Capra*; *Bos*;		XXXI
Abruzzo	37	Le Coste	MBA	Agriculture; Wood Procurement	*Triticum hulled*; *Hordeum*;	*Quercus robur*; *Quercus ilex*; *Quercus cerris*; *Fagus*; *Ostrya caprinifolia*; *Phragmites australis*;				XXXII
Puglia	198	Madonna del Petto	LBA	Agriculture	*Hordeum*; *Triticum hulled*; *Triticum naked*; *Cfr. Secale*; *Pulses*;					XXXIII
Puglia	297	Masseria Chiancudda	MBA	Wood Procurement		*Arbutus unedo*; *Erica cfr. Multiflora*; *Olea europaea*; *Pistacia lentiscus*; *Quercus robur*; *Quercus ilex*; *Rhamnus/ Phillyrea*; *Rosaceae/ Maloideae*; *Juniperus*; *Pinus*;				XXXIV
Molise	87	Masseria Mammarella	LBA	Agriculture; Harvesting; Hunting	*Hordeum*; *Triticum hulled*; *Pulses*;		*Quercus robur*; *Rubus*; *Vitis silvestris*;	*Ovis/Capra*; *Sus domesticus*; *Bos*;	*Lepus* sp.; *Cervus*; *Aves*; *Capreolus*;	XXXV

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XXVIII De Grossi Mazzorin and Minniti 2003.
XXIX *Ibidem*.
XXX *Ibidem*.
XXXI *Ibidem*.
XXXII Angeli *et alii* 2011; Castiglioni and Rottoli 2003.
XXXIII Primavera *et alii* 2017.
XXXIV *Ibidem*.
XXXV Barker 1995, p. 132.

Puglia	258	Mola di Bari	MBA	Wood Procurement; Agriculture; Hunting; Breeding	*Hordeum*; *Triticum hulled*; *Triticum naked*; *Pulses*;	*Acer*; *Erica cfr. multiflora*; *Ostrya/ Carpinus*; *Olea europaea Pistacia lentiscus*; *Prunoideae*; *Quercus ilex*; *Coniferae*; *Rhamnus/ Phillyrea*; *Quercus robur Pinus*;		*Bos*; *Ovis/Capra*;	*Cervus*;	XXXVI
Puglia	264	Monopoli - Centro storico	MBA	Wood Procurement; Agriculture; Harvesting	*Hordeum*; *Triticum hulled*; *Pulses*;	*Corylus/ Alnus*; *Fraxinus* sp.; *Pistacia lentiscus*; *Quercus robur*;	*Olea europaea*; *Quercus robur*; *Ficus carica*;			XXXVII
Puglia	264	Monopoli - Centro storico	LBA	Wood Procurement; Agriculture; Harvesting	*Hordeum*; *Triticum hulled*; *Triticum naked*; *Pulses*;	*Olea europaea*; *Prunoideae*; *Populus Salix*; *Quercus robur*; *Quercus ilex*; *Rhamnus/ Phillyrea*;	*Olea europaea*; *Quercus robur*; *Ficus carica*;			XXXVIII
Molise	72	Oratino - La Rocca	LBA	Agriculture; Harvesting; Wood Procurement; Breeding; Hunting	*Triticum hulled*; *Triticum naked*; *Hordeum*; *Pulses*;	*Quercus robur*; *Carpinus*; *Quercus cerris*; *Quercus ilex*; *Boxus*; *Ficus*; *Corylus*; *Salix/ Populus*; *Laburnum* sp.; *Acer* sp.; *Rosaceae*; *Ulmus* sp.; *Vitis vinifera*;	*Juglans regia*;	*Equus caballus*; *Ovis/Capra*; *Bos*; *Sus domesticus*;	*Cervus*; *Sus scrofa fer.*; *Testudo*; *Lepus* sp.;	XXXIX
Puglia	336	Punta le Terrare	MBA	Breeding				*Sus domesticus*; *Bos*; *Ovis/Capra*;	*Cervus*; *Testudo*;	XL

→

[XXXVI] Primavera *et alii* 2017; Radina 2010.
[XXXVII] Primavera *et alii* 2017.
[XXXVIII] *Ibidem*.
[XXXIX] Buglione and De Venuto 2008; D'Oronzo and Fiorentino 2008.
[XL] De Grossi Mazzorin *et alii* 2017.

Puglia	318	Rissiedi	MBA-LBA	Breeding; Hunting				*Ovis/Capra*; *Sus domesticus*; *Bos*;	*Cervus*; *Testudo*;	[XLI]
Puglia	357	Roca	MBA	Wood Procurement		*Olea europaea*; *Myrtus communis*; *Ligustrum vulgare*; *Prunoideae*; *Quercus robur*; *Quercus ilex*; *Juniperus*;				[XLII]
Puglia	262	San Domenico	MBA	Wood Procurement; Agriculture	*Triticum* sp.; *Hordeum*; *Pulses*;	*Olea europaea*; *Prunoideae*; *Quercus ilex*;				[XLIII]
Puglia	357	Roca	LBA	Agriculture; Harvesting	*Hordeum*; *Triticum hulled*; *Triticum naked*; *Pulses*;		*Quercus robur*;			[XLIV]
Puglia	262	San Domenico	LBA	Agriculture	*Hordeum*; *Triticum* sp.; *Triticum hulled*; *Triticum naked*; *Panicum*; *Pulses*;					[XLV]
Puglia	335	Scalo di Furno	MBA	Wood Procurement; Agriculture	*Triticum hulled*; *Triticum naked*; *Hordeum*; *Pulses*;	*Arbutus unedo*; *Ericaceae*; *Cotynus coggigria*; *Olea europaea*; *Myrtus communis*; *Quercus robur*; *Quercus ilex*; *Prunoideae*; *Rhamnus/ Phillyrea*;	*Quercus robur*;			[XLVI]
Puglia	327	Torre Santa Sabina	LBA	Agriculture	*Hordeum*; *Triticum hulled*; *Triticum naked*;					[XLVII]

→

[XLI] Coppola 1983.
[XLII] Primavera *et alii* 2017.
[XLIII] *Ibidem*.
[XLIV] *Ibidem*.
[XLV] Primavera *et alii* 2017.
[XLVI] *Ibidem*.
[XLVII] *Ibidem*.

Abruzzo	18	Trasacco 1	BR	Breeding; Hunting				*Bos*; *Sus domesticus*; *Ovis/Capra*; *Equus caballus*;	*Sus scrofa fer.*; *Cervus*; *Capreolus*;	[XLVIII]
Abruzzo	14	Celano Paludi	BF	Hunting; Breeding; Agriculture	*Triticum hulled*; *Triticum naked*; *Proso millet*; *Pulses*;	*Quercus* sp.; *Salix* sp.; *Populus* sp.; *Ostrya caprinifolia*; *Fagus*; *Acer* sp.; *Fraxinus*; *Juniperus*; *Taxus sp.*	*Corylus avellana*; *Cornus mas*; *Quercus robur*; *Rubus*; *Sambucus nigra*;	*Equus caballus*; *Bos*; *Sus domesticus*; *Ovis/Capra*;	*Cervus*; *Aves*; *Capreolus*; *Canis lupus*; *Sus scrofa fer.*;	[XLIX]
Abruzzo	68	Fonte Tasca	BF	Breeding				*Ovis/Capra*; *Bos*; *Sus domesticus*;		[L]
Abruzzo		Grotta Sant'Angelo	LBA	Breeding; Hunting				*Ovis/Capra*; *Bos*;	*Lepus* sp.; *Cervus*; *Capreolus*; *Sus scrofa fer.*;	[LI]
Abruzzo	53	Madonna degli Angeli	BF	Agriculture; Breeding; Hunting	*Triticum hulled*; *Triticum naked*; *Hordeum*;			*Ovis/Capra*; *Sus domesticus*; *Bos*; *Equus caballus*;	*Cervus*; *Capreolus*; *Ursus arctos*; *Testudo*;	[LII]
Abruzzo	74	Punta d'Erce	BF-IFE	Breeding; Hunting; Fishing				*Bos*; *Ovis/Capra*; *Sus domesticus*;	*Cervus*; *Sus scrofa fer.*; *Testudo*; *Mollusca*;	[LIII]
Puglia	273	Torre Castelluccia	BF	Agriculture; Viticulture	*Hordeum; Triticum hulled; Triticum naked; Pulses; Vitis Vinifera;*					[LIV]

[XLVIII] De Grossi Mazzorin and Minniti 2003; Wilkens 1991.
[XLIX] Coubray 1991; De Grossi Mazzorin 1991; De Grossi Mazzorin and Minniti 2003.
[L] De Grossi Mazzorin 1998.
[LI] De Grossi Mazzorin and Minniti 2003; Iaconis and Boschian 2007.
[LII] De Grossi Mazzorin and Minniti 2003; Mieli *et alii* 2003.
[LIII] De Grossi Mazzorin and Minniti 2003.
[LIV] Primavera *et alii* 2017.

Table 2. - Overview of case studies providing botanical and faunal records. Sites appear multiple times when distinct archaeobotanical or zooarchaeological datasets are available for different phases. Documented activities reflect the nature and resolution of available evidence and are not directly comparable across sites.

dataset of botanical and archaeobotanical records for the Italian peninsula, served as valuable resource for acquiring data and key literature references [8]. Some case studies provide data for different chronological phases; therefore, they appear multiple times in the table 2.

[8] Mercuri *et alii* 2024.

Topographic feature	data type	Source	Resolution	Processing
DEM	Raster	(European Space Agency and Sinergise, 2021)	25m	none
Classified DEM	Raster	Processing EU-DEM	25m	Classify() function – terra package in R (Hijmans 2025)
Slope	Raster	Processing EU-DEM	//	Terrain function – raster package in R (Hijmans, 2023)
Aspect	Raster	Processing EU-DEM	//	Terrain function – raster package in R (Hijmans, 2023)
TRI	Raster	Processing EU-DEM	//	Terrain function – raster package in R (Hijmans 2023)
TPI	Raster	Processing EU-DEM	//	Terrain function – raster package in R (Hijmans, 2023)
Valley depth	Raster	Processing EU-DEM	//	Tool Valley Depth SAGA-GIS (Conrad 2012)
Coastline distance	Raster	Processing EU-DEM	//	Movecost package in R (Alberti 2019)
Inland waterbodies distance	Vector	Rivers shapefile (Lehner *et alii* 2008)		distance_to function – distanceto packge R (Robitaille 2023)

Table 3. -Topographic features, data sources, and processing methods used in the analysis.

2. Processed topographic and environmental data

Settlement pattern analysis and MaxEnt modelling have been conducted using a combination of selected environmental features represented in both raster and vector data formats, differently combined according to the type of analysis. These include both primary sources, such as the digital elevation model, and modelled data derived from analytical processes. These datasets can be grouped into four main groups: terrain features (topography), hydrology, soil characteristics and thermotypes.

2.1. *Terrain characteristics*

Site locations were topographically characterised on the basis of measurable, low-changeability features. The primary raster source used is the EU-DEM Copernicus Digital Elevation Model with a 25 m resolution [9], while slope, aspect ratio, TPI, TRI and valley depth have been obtained by modelling the DEM (Tab. 3). In addition, two vector layers have been used to assess site distances from inland water bodies and the coastline.

Classified Digital Elevation Model

The original DEM was reclassified into six elevation classes using the classify function (Tab. 3). This variable serves as a proxy for differentiating ecological niches, as elevation strongly influences factors such as climate, vegetation, resource availability, and accessibility, all of which conditioned settlement choices and human activities. It was analysed in combination with other environmental factors, such as distance from the coastline, to enhance the understanding of ecological influences on site distribution.

Class	Elevation Range (m asl)
1	0 – 100
2	100 – 200
3	200 – 500
4	500 – 1000
5	1000 – 1500
6	>1500

Table 4. - Elevation classes used in the DEM reclassification.

Slope and Aspect

Slope and Aspect are widely adopted topographic features in landscape archaeology. Slope measures the steepness of terrain by calculating elevation changes in a Digital Elevation Model (DEM). It influences water runoff, erosion, and land suitability, with steeper slopes being less favorable for agriculture and settlement. Aspect defines the direction a slope faces (0° = north, 90° = east, 180° = south, 270° = west), affecting solar exposure, moisture retention, and vegetation growth. In the Northern Hemisphere, south-facing slopes receive more sunlight, making them preferable for habitation and cultivation.

[9] European Space Agency and Sinergise 2021.

Terrain Ruggedness Index (TRI)

The Terrain Ruggedness Index (TRI) is a topographic variable that quantifies the variation in elevation within a given area. It measures the difference between a central pixel and its surrounding pixels in a Digital Elevation Model (DEM), providing insights into landscape roughness [10]. Higher TRI values indicate more rugged terrain, while lower values correspond to flatter areas.

TPI (Topographic position index)

TPI (Topographic position index) is an effective algorithm method to quantify topographic positions and to automate landform classifications [11]. Processing the DEM data, it measures the relative elevation difference between a central point and those around basing on pre-set *radius* (w). Output is a classified grid-raster in which to each cell is assigned a TPI value: positive values indicates that central point is higher in elevation than those around, *vice versa,* negative values indicate hollowed locations. The larger the set *radius* value is, the larger the landscape units revealed by the analysis are; conversely, smaller *radius* values reveal smaller landform characteristics. This analysis has been performed on a wide-range scale (i.e., regional scale) following procedure indicated by Nakoinz and Knitter [12].

Valley depth

Valley depth measures the difference between the elevation of a given point and an interpolated ridge level. The ridge level is determined using the 'Vertical Distance to Channel Network' tool, which identifies ridge cells based on the Strahler order applied to an inverted Digital Elevation Model (DEM). An interpolated ridge surface is then generated, and valley depth is calculated by subtracting the original elevation from this ridge level [13].

Distance from the coastline

The use of slope-based cost function is currently employed as valuable proxies for exploring the degree of potential movements around inhabited places of the past [14]. The slope based on anisotropic cost-surface analysis has been adopted in this study for classifying case studies into "coastal", "subcoastal", and "inland" contexts, this improves on conventional categorization methods reliant on Euclidean distances by integrating time expenditure-based models;

The analysis has been performed by the *movecost* package in R [15] using the raster DEM indicated in the previous paragraph. Travel-time surfaces were calculated by applying the time-based Tobler's on-path hiking function [16].

Distance from Inland Waterbodies

Distances from the inland water bodies was measured using geodesic distance, calculated with the *distance_to* function from the *distanceto* package in R [17]. Inland water bodies include both present-day watercourses, derived from the Rivers Shapefile, and ancient lakes or lagoons reconstructed from geomorphological studies, such as the Fucino Basin and the Salpi Lagoon.

2.2. *Hydrology*

The Topographic Wetness Index (TWI) is a widely used hydrological variable that quantifies the potential for water accumulation in a given area based on terrain attributes [18]. It is particularly relevant in landscape archaeology as it helps assess settlement choices, agricultural potential, and environmental constraints.

It is derived from a Digital Elevation Model (DEM) and is calculated as a function of the contributing area (catchment size) and local slope, expressing the balance between water inflow and drainage capacity. Higher TWI values indicate areas prone to water retention, such as valleys and depressions, whereas lower values are associated with well-drained locations like ridges and slopes. The Topographic Wetness

$$TWI = \ln\left(\frac{A}{\tan b}\right)$$

Index (TWI) is mathematically expressed as:

where A represents the specific catchment area (the upslope contributing area per unit width), and b is the slope angle. This formula quantifies the balance

[10] Riley *et alii* 1999, p. 199; Trevisani *et alii* 2023.

[11] De Reu *et alii* 2013.

[12] Nakoinz and Knitter 2016, p. 112.

[13] Conrad 2012.

[14] Lewis 2024.

[15] Alberti 2019.

[16] Irmischer and Clarke 2018; Pingel 2010.

[17] Robitaille 2023.

[18] Riihimäki *et alii* 2021; Winzeler *et alii* 2022.

between water accumulation and drainage capacity, making TWI a key variable in hydrological and landscape analysis.

In this study, TWI was computed using a DEM-based approach in R, leveraging the *Whitebox* package [19]. The analytical workflow follows the methodology outlined in Lindsay's work *WhiteboxTools User Manual* [20].

2.3. *Soil features*

In addition to the quantitative characterization of the landscape, this research incorporates qualitative soil features by extracting the Web Feature Service (WFS) of the 'Ecopedological Map' for the study area from the web map of the 'Ministero dell'Ambiente e della Sicurezza Energetica' (MASE) (Geoportale Nazionale: [http://www.pcn.minambiente.it/viewer/]). The Ecopedological Map of Italy is a thematic map developed to characterise Italian soils concerning their hydrological properties, erosion risks, soil-vegetation relationships, and conservation aspects.

The utilization of this source has been specifically directed towards the MaxEnt modelling process, as it offers integrated ecological data that may influence economic practises. To accommodate the requirements of MaxEnt, which necessitates raster data for generating predictive maps, the map has been converted into classified raster format.

2.4. *Thermotypes as climatic variables in landscape modelling*

This study integrates a novel climatic variable into the MaxEnt modelling process: thermotypes, derived from the Worldwide Bioclimatic Classification System (WBCS) [21] as applied to the Italian peninsula [22].

At an initial stage of the analysis, I incorporated bioclimatic variables from the Beyer at al. 2020 dataset using the 'pastclim' package in R [23]. However, this approach proved to be of limited use at the scale of this study. The resulting grid rasters, even after resampling, appear more reliable for larger spatial contexts – such as continental or subcontinental scales – rather than for the macroregional extent of this research.

On the other hand, thermotypes are defined through the compensated thermicity index (*Itc*) and thresholds of positive temperatures (*Tp*), offering a high resolution view of temperature-related constraints over the study area. They summarise the average thermal conditions in a way that aligns with vegetation zonation and agricultural potential. Crucially, thermotypes reflect not only absolute temperatures but also their seasonal amplitude and biological relevance – factors highly significant in determining the suitability of specific areas for cultivation, pasture, or year-round habitation.

In this study, thermotypes map were used as a categorical environmental covariate in the MaxEnt modelling. By treating thermotypes as spatial proxies for ecological envelopes, it becomes possible to test whether communities showed a preference for, or avoidance of, particular climatic zones a local scale. For example, the Supramediterranean and Mesomediterranean zones might have offered reliable rainfall and moderate seasonal variability, favouring certain crops and pastoral strategies, whereas the Thermomediterranean belt may have been better suited for perennial plant exploitation or winter grazing.

The inclusion of thermotypes serves two main purposes. First, it provides a robust summary of long-term seasonal dynamics, which are known to have played a key role in structuring prehistoric economies and mobility regimes. Second, it allows for a more interpretable form of climatic modelling, where each category corresponds to a clearly defined ecological condition, enhancing the integration of the MaxEnt results with archaeological and palaeoeconomic interpretations.

3. MaxEnt: principles and practical application

MaxEnt (Maximum Entropy) is widely known as a machine learning method falling into ecoinformatics category of Species Distribution Models (SDMs) [24]. Yet, it was first introduced in statistical mechanics [25] and later adapted for various applications, including ecology and geographical modelling. Unlike traditional presence-absence regression approaches, MaxEnt does not require absence data but instead relies on presence-only data to estimate relative suitability patterns for a given phenomenon.

[19] Lindsay 2016.

[20] Weblink: https://www.whiteboxgeo.com/manual/wbt_book/available_tools/hydrological_analysis.html.

[21] Hijmans *et alii* 2005; Rivas-Martìnez 2008; Rivas-Martìnez *et alii* 2011.

[22] Pesaresi *et alii* 2014.

[23] Beyer *et alii* 2020; Krapp *et alii* 2021; Leonardi *et alii* 2023.

[24] Elith *et alii* 2006; Merow *et alii* 2013; Phillips and Dudík 2008; Radosavljevic and Anderson 2014.

[25] Jaynes 1957.

BOX 1

Maximum Entropy Principle

MaxEnt estimates the probability distribution $\pi(x)$ that maximizes entropy while constrained by known environmental data. The Shannon entropy is given by:

$$H(\pi) = -\sum_{x \in X} \pi\,(x) \ln \pi(x)$$

where:

- $\pi(x)$ is the probability of occurrence at location x,
- X is the set of all possible locations.

The goal is to find $\pi(x)$ that maximizes $H(\pi)$ while ensuring that expected environmental values match the observed data.

Constrained Optimization & Probability Distribution

The final probability distribution $\pi(x)$ that satisfies these constraints follows a Gibbs distribution:

$$\pi(x) = \frac{e^{\sum_j \lambda_j f_j(x)}}{Z}$$

where:

- λ_j are the coefficients (weights) associated with environmental predictors,
- $f_j(x)$ are feature functions of the environmental variables (e.g., elevation, distance to water),
- Z is a normalization constant (partition function) ensuring probabilities sum to 1:

$$Z = \sum_{x \in X} e^{\sum_j \lambda_j f_j(x)}$$

This ensures that MaxEnt chooses the least biased distribution that aligns with empirical constraints.

Regularization to Prevent Overfitting

To avoid overfitting, MaxEnt applies L1 regularization (similar to Lasso regression):

$$\ell(\lambda) = \sum_{i=1}^{m} \ln \pi(x_i \mid \lambda) - \beta \sum_{j} \mid \lambda_j \mid$$

where:

- x_i are the observed presence points
- β is a regularization parameter that controls model complexity.

This step ensures that models remain parsimonious and generalise well to unseen data.

BOX 2

- ***Data Preparation***
  - *Import, preprocess, and standardize spatial and environmental data.*
    - *Import sites dataset and study area boundary.*
    - *Import raster datasets (topography, climate, soil, etc.).*
    - *Resample rasters to ensure a uniform resolution.*
    - *Aggregate rasters where necessary to reduce computational complexity.*
    - *Crop environmental layers to the study area extent.*
- ***Construct Spatial Dataset***
  - *Categorize presence points by phase.*
- ***Define Model Parameters***
  - *Set MaxEnt configurations, including buffer size, feature selection, and regularization.*
    - *Set buffer size to define the extent of background sampling.*
    - *Select feature types (Linear, Quadratic, Hinge) to control model complexity.*
    - *Apply regularization (e.g., $\beta = 1.5$) to prevent overfitting.*
    - *Enable cross-validation to improve model reliability.*
- ***Generate Background Points***
  - *Sample background points within the study area using a buffer around presence points.*
    - *Generate a buffered study area around presence points.*
    - *Randomly sample background points from within the study extent.*
    - *Ensure the background sample is representative of environmental variability.*
- ***Train-Test Data Splitting***
  - *Randomly split presence data into training (50%) and testing (50%) subsets.*
- ***Extract Environmental Variables***
  - *Extract environmental predictor values at presence and background points.*
- ***Prepare Training Dataset***
  - *Format extracted data into a MaxEnt-compatible dataset with presence/absence labels.*
- ***Train MaxEnt Model***
  - *Train the MaxEnt model using presence and background environmental data, applying cross-validation to assess robustness.*
    - *Fit the model using training occurrence and background data.*
    - *Optimize the model by iteratively adjusting feature selection and regularization.*
    - *Perform cross-validation to test model stability.*
- ***Predict Probability Distribution***
  - *Generate suitability maps by applying the trained model to environmental layers.*
    - *Apply the trained MaxEnt model to entire environmental layers.*
    - *Produce continuous probability maps where each pixel represents habitat suitability.*
- ***Model Evaluation***
  - *Evaluate model performance using cross-validation, AUC, response curves, and jackknife tests.*
    - *Compute AUC (Area Under the Curve) to evaluate discrimination ability:*
    - *Training AUC: Fit to training data.*
    - *Testing AUC: Generalization performance.*
    - *Generate response curves to analyse environmental variable influence.*
    - *Perform jackknife tests to assess variable importance.*
    - *Compare cross-validation results to check model consistency.*

Main outcomes include classified maps (raster data), where grid cells are assigned a score representing predicted suitability for the analysed spatial phenomenon based on the input conditions. Additionally, resulting response curves illustrate how each – environmental – variable influences the probability of presence, helping to identify thresholds at which certain variables become more or less significant in determining site suitability.

Beyond its application in ecological studies, MaxEnt has also been applied to predict a variety of spatial phenomena [26]. In recent years its application to different geographical and chrono-cultural contexts – from hunter-gatherer societies to the analysis of settlement patterns in agropastoral communities – has demonstrated its potential for landscape archaeology [27].

The approach is based on the principle of maximum entropy, which states that when making predictions with incomplete information, one should select the probability distribution that is most spread out (closest to uniform), subject to known constraints. As this book is primarily addressed to an archaeological audience, the mathematical principles are presented here in a simplified form (Box 1), while a full technical treatment can be found in the specific literature [28].

The analysis has been performed by the package "*dismo*" in R [29]. The package is a powerful tool for species distribution modelling (SDM), providing a streamlined workflow for automating key modelling steps. It simplifies environmental data processing and extraction, enabling researchers to efficiently retrieve predictor values at presence and background locations [30]. The code used for this analysis is available on the GitHub project page [31], while the main processing steps are outline in the Box 2.

Performance and reliability of resulting MaxEnt models have been evaluated by the use of combined evaluation tests:

• *Cross-validation*: Splits the dataset into multiple training and testing subsets to test the model's consistency and reduce bias. It ensures that the model's predictions are not overly dependent on a specific data sample [32];

• *AUC (Area Under the Curve):* Measures the model's ability to distinguish between suitable and unsuitable areas. A higher AUC (closer to 1) indicates better predictive performance;

• *Response curves*: Show how each environmental variable influences the probability of presence, helping to interpret variable importance and detect non-linear relationships;

• *Jackknife tests*: Evaluate the contribution of each environmental predictor by systematically omitting variables and assessing their impact on model performance [33]. This helps identify the most influential factors.

[26] Liao *et alii* 2017.

[27] Demján *et alii* 2022; Franklin *et alii* 2015; Rafuse 2021; Wachtel *et alii* 2018.

[28] Elith *et alii* 2011; Phillips *et alii* 2006.

[29] Hijmans *et alii* 2023.

[30] If you are interested in testing this type of analysis for archaeological studies, new tools are also available (Leonardi *et alii* 2024a).

[31] https://enricolucci.github.io/MODLAND-R-code-for-MaxEnt/

[32] Lovelace *et alii* 2019, p. 242.

[33] Ramachandran and Tsokos 2020, p. 532.

4.
From data to models: exploring settlement and landscape dynamics

This chapter introduces the first of two complementary analytical levels developed in this research. Its aim is to establish a cumulative and standardised framework through which large-scale patterns in settlement distribution can be explored across time and space (fig. 1), while the contextual interpretation of specific territorial cases is addressed in Chapter 5.

The analysis therefore opens with the definition of a chronological framework, which provides the temporal structure for the subsequent spatial investigations. Pottery traditions provided the basis for assigning sites to cultural phases, but these phases were reorganised into broader analytical categories to avoid excessive fragmentation, particularly for the Copper Age. In this sense, the categories adopted here function as analytical time windows rather than rigid cultural boundaries: transformations in human-landscape relations did not necessarily follow the limits marked by ceramic traditions. This pragmatic solution allowed the dataset to remain coherent and comparable while providing a basis for testing settlement dynamics across millennia (§ 1).

Distribution maps and Kernel Density Estimation (KDE) were used to visualise shifts in settlement intensity, while Cross-K functions tested continuity and reorganisation between successive phases (§ 1). These spatial results were integrated with demographic trends derived from Summed Probability Distributions (SPD) of radiocarbon dates, offering an independent line of evidence for long-term population dynamics (§ 2).

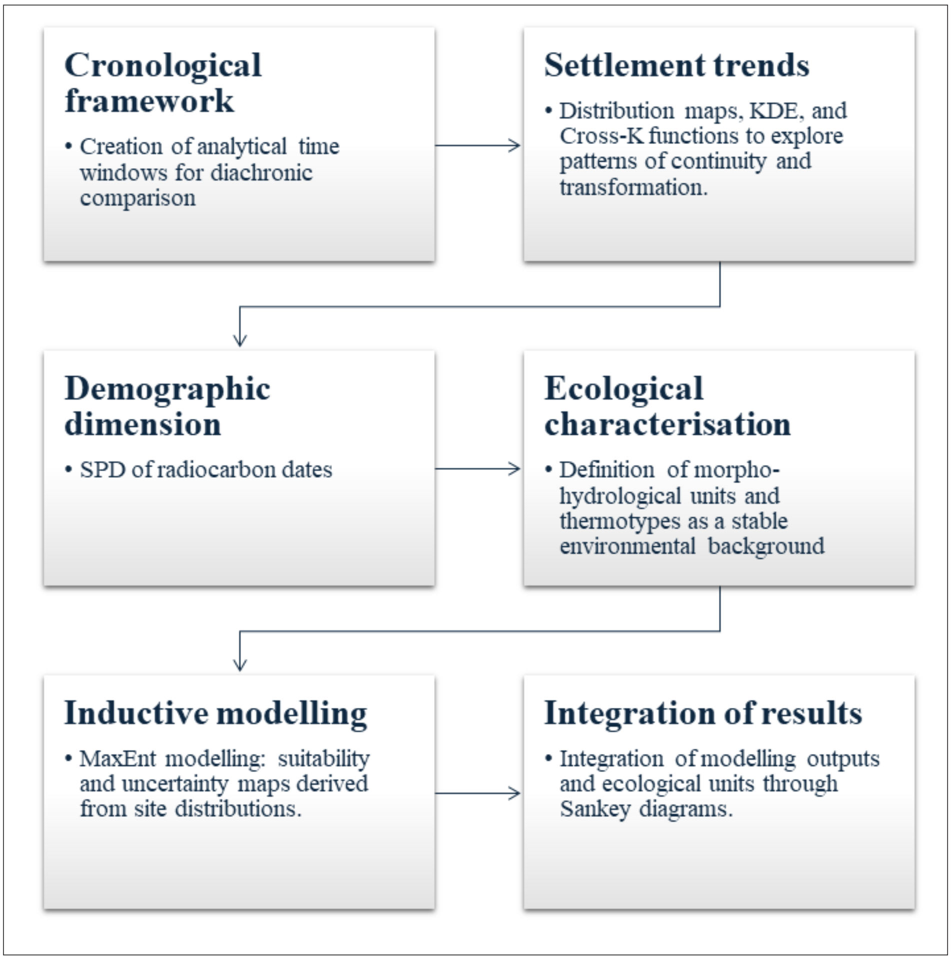

Fig. 1. - Analytical workflow of Chapter 4, outlining the steps used to construct models and investigate broad-scale settlement dynamics.

To further explore the ecological dimension of settlement choices, the study area was classified into morpho-hydrological units and interpolated with climatic belts (thermotypes), providing a stable environmental background for interpretation (§ 3). On this basis, phase-specific MaxEnt models were produced to identify areas of higher or lower settlement suitability, with explicit representation of model uncertainty (§ 4). Finally, these probabilistic surfaces were compared with the ecological classifications using Sankey diagrams and cross-comparison, in order to assess how suitability patterns intersected with different types of morpho-hydrological units and climate (§ 5).

Together, these steps provide an analytical framework linking broad chronological trends, demographic fluctuations, ecological settings, and inductive modelling, thereby establishing the basis for the more detailed, contextual discussions developed in Chapter 5.

1. Chronological trends: counting and comparing site distributions across periods

In this study, chronocultural uncertainties have been addressed by organising the case studies into clearly defined chronological segments (Tab. 1). This categorisation was applied whenever the source publications provided robust archaeological data. In instances where such data were insufficient, sites were either labelled generically as "*Copper Age nd*" or "*Bronze Age nd*". To ensure analytical comparability and to avoid excessive fragmentation of the spatial dataset, Copper Age contexts were therefore grouped into broader chronological divisions - namely the Early Copper Age (ECA, corresponding to the 4th millennium BCE) and the Late Copper Age (LCA, corresponding to the 3rd millennium BCE). This decision reflects both the relatively limited number of well-documented Copper Age contexts and the higher degree of chronological uncertainty characterising this period.

A large portion of the dataset consists of case studies that can be assigned to specific chronological segments (fig. 2). Most of these belong to the Bronze Age, which underlines the limited knowledge we have of Copper Age settlements. The '*nd*' categories for both the Copper and Bronze Ages account for a considerable number of the sites, primarily because many have not been systematically investigated or lack diagnostic elements. To aid interpretation, the data were mapped (fig. 3) to visualise the spatial distribution of sites across the principal defined chrono-cultural phases.

Simple distribution maps already offer a useful first impression. They help to intuitively grasp the varying reliability of the datasets for each chronological phase and to identify some broad patterns of change at a macro-regional scale as well as biases of different kinds, such as the uneven quantity of data across periods.

To better understand the dynamics of spatial pattern transformation, Kernel Density Estimation (KDE) maps are employed (fig. 4), based on the entire available cumulative dataset of sites per chronological period. To ensure comparability across chronological phases, all Kernel Density Estimation (KDE) maps share a common colour scale. Minimum and maximum raster values were computed once and applied uniformly across all plots.

One of the first aspects to note in these maps is the strong impact of research bias across different territories, since surveyed areas are likely to exert a disproportionately greater influence on density estimates

For example, the constant presence of a cluster close to the southeastern coast is related to the high number of sites detected by the survey project in area of Cisternino (see fig. 1, chapter 3 – survey area n°7). Moreover, scattered clusters of generic Copper Age sites (*Copper Age nd*) in some way counterbalance the lack of sites both for the 4th and 3rd millennia

Phase	Chronology
Early Copper Age (ECA)	4th mill. cal. BCE
Late Copper Age (LCA)	3rd mill. cal. BCE
Early Bronze Age (EBA)	20th - 16th cen. cal BCE
Middle Bronze Age (MBA)	15th - 14th cen. cal. BCE
Late Bronze Age (LBA)	13th - 12th cen. cal. BCE
Final Bronze Age (FBA)	11th cen. cal. BCE

Table 1. - Categories for quantitative analysis of chronological distribution of the case studies.

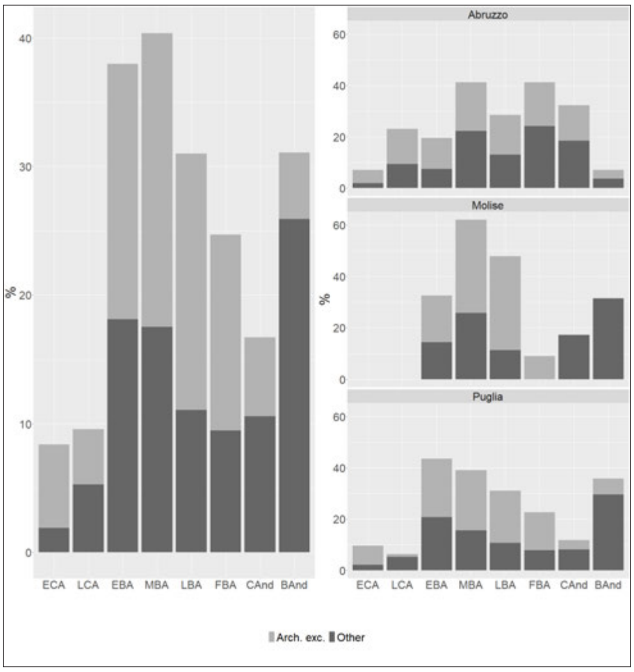

Fig. 2. - Percentage of case studies per chronological phase, according to the type of investigation: on the left, the cumulative trend for the entire study area, on the right, the regional trends.

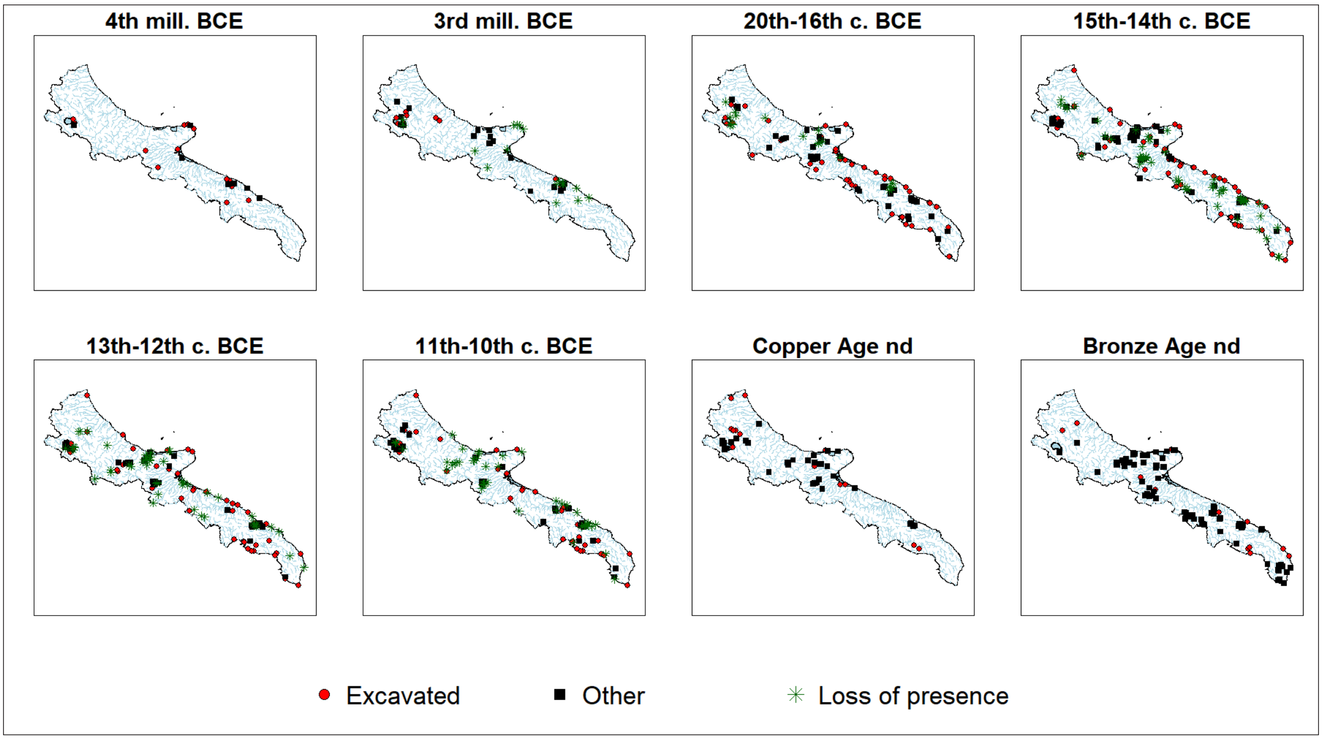

Fig. 3. - Spatial distribution of case studies during the different analysed chronological phases: red dots represent excavated sites, black squares represent sites identified through surveys and surface collections, and green asterisks indicate sites that were occupied in previous phase(s) but abandoned in the corresponding phase.

BOX 3

- **Univariate (Ripley's K):**

$$K(r) = \frac{1}{\lambda} \cdot E[\text{number of other points within distance } r]$$

r]

- **Cross-type (K_{ij}):**

$$K_{ij}(r) = \frac{1}{\lambda_j} \cdot E[\text{number of type-}j\text{ points within distance } r \text{ of a type-}i\text{ point}]$$

Where:

- λ is the intensity (density) of all points (used in univariate K).
- λ_j is the intensity (density) of type-jjj points (used in cross-type K_{ij}).

BCE. This standardised scale reveals patterns of stability and transformation in settlement distribution: a notable increase in spatial spread during the Middle and Late Bronze Age is followed by a contraction in the Final Bronze Age, reflecting the trend previously highlighted (fig. 2). However, maps (fig. 3) also stress the increasing importance of coastal areas starting from the early 2^{nd} mill. BCE.

To formalise and visualise the diversification of spatial distributions between adjoining chronological phases (for example between LCA and the EBA, and between EBA and MBA and so on) Cross K-function was applied. The Cross K function (K_{ij}) is a direct extension of Ripley's K function, it is a second-order spatial statistic used to assess the spatial relationship between two different types of points in a space, from intrasite to site distribution analysis [1]. It enables the assessment of whether sites of phase *j* occur more or less frequently around sites of phase *i* than expected under spatial randomness. The analysis was performed in R using the package *spatstat* [2].

[1] Chiu *et alii* 2013; Dixon 2014; Kan *et alii* 2022; Sayer and Wienhold 2012; Stoyan and Stoyan 1996; Tang *et alii* 2015; Van Lieshout and Baddeley 1999.

[2] Baddeley and Turner 2005.

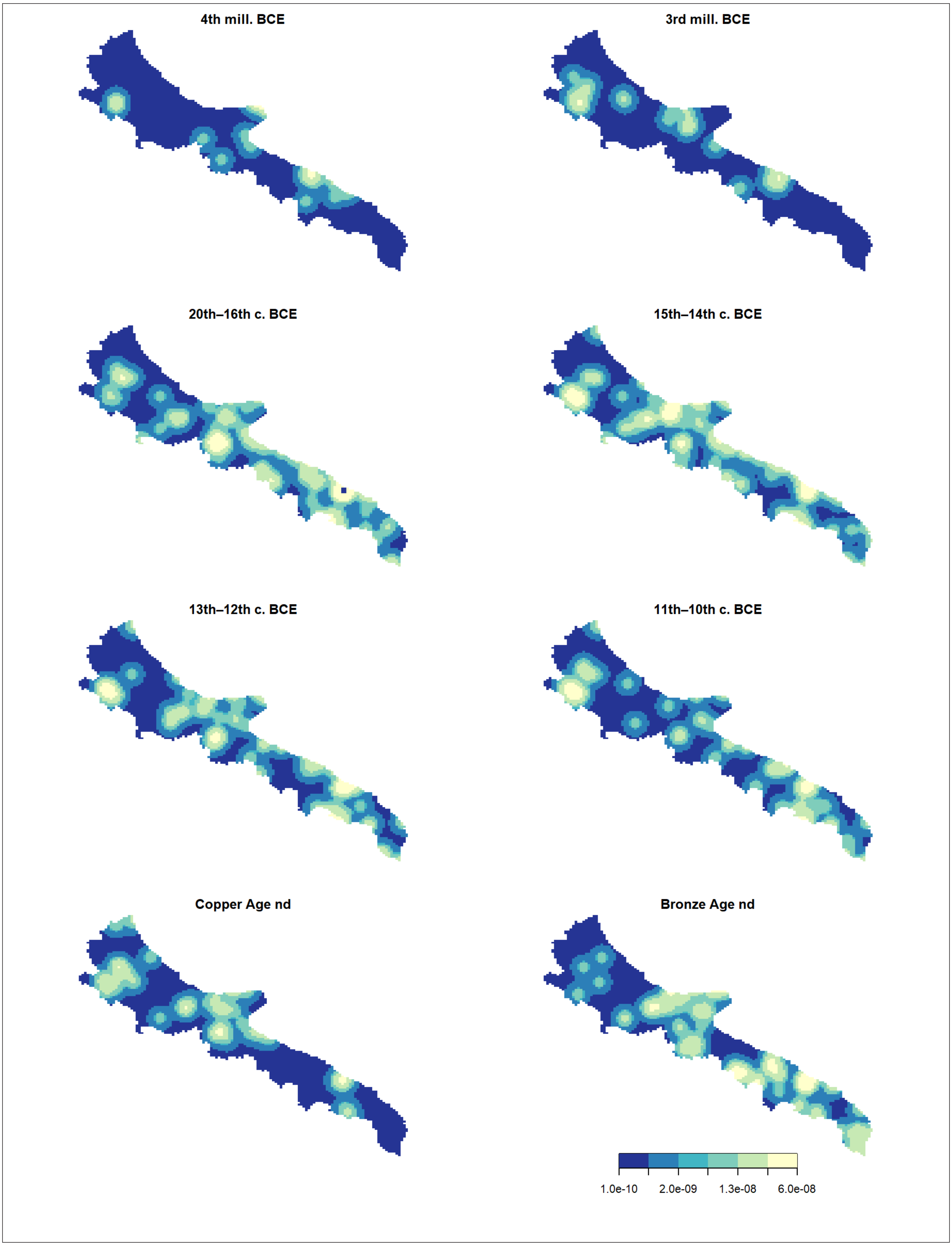

Fig. 4. - Kernel Density Estimation (KDE) maps of the spatial datasets for each chronological period under analysis (bandwidth = 7000 m).

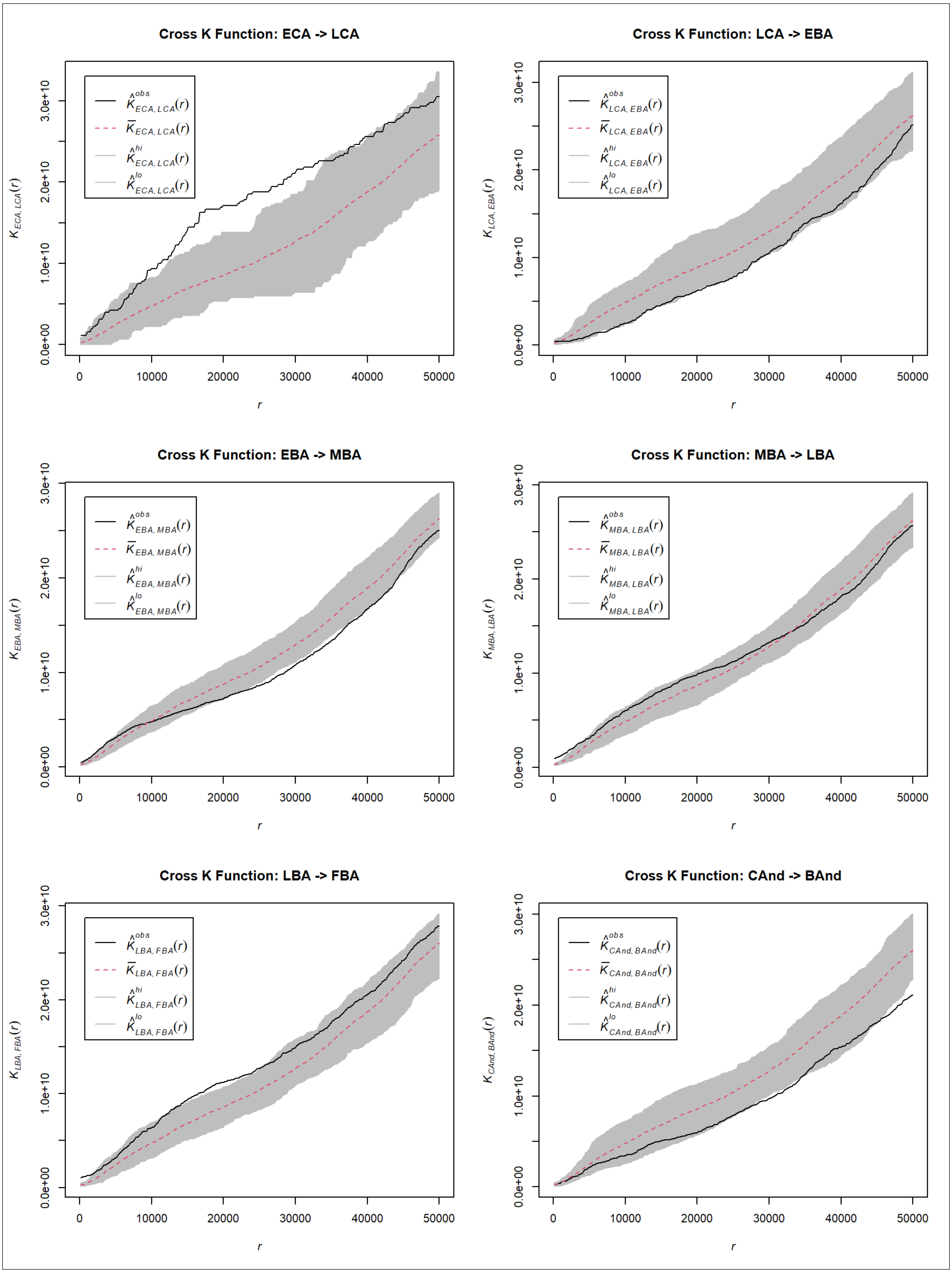

Fig. 5. - Cross K function for the spatial dataset across chronological phases. Monte Carlo envelopes, based on 99 random relabelling simulations, indicate the expected range of spatial association under the assumption of randomness. The black solid line represents the observed K function. The red dashed line indicates the mean K function under Complete Spatial Randomness (CSR), based on 99 Monte Carlo simulations. The grey shaded area is the envelope, representing the range of variation across simulations (approx. 95% confidence interval). If the black line lies: (i) above the envelope, it indicates spatial attraction (i.e. sites of phase j tend to cluster around those of phase i more than expected by chance); (ii) below the envelope, it indicates spatial repulsion (i.e. sites of phase j avoid those of phase i); (iii) within the envelope, it indicates no significant spatial relationship, consistent with randomness.

K-function was selected within the diversified range of second-order spatial statistics [3] since better fits in the inquiries of this analysis, assessing the degree of transformation of human presence into the landscape by taking into account different scales (*r*) and the entire dataset. Rather than focusing solely on localised proximities, this approach captures broader spatial dynamics by assessing the cumulative density of later-phase sites around those of earlier periods. To assess the statistical significance of the observed spatial patterns, Monte Carlo envelopes were generated through 99 random relabelling simulations.

Outcomes (fig. 5) reveal a diversified trajectory of continuity and transformation that reflects both long-term structuring processes and moments of significant reorganisation.

The earliest chronological transition analysed – between the Early and Late Copper Age – displays a clear pattern of spatial attraction, suggesting that places occupied in the earlier phase retained their relevance into the later one. However, this pattern does not persist uniformly across subsequent phases. The shift to the Early Bronze Age coincides with a degree of transformation, as no clear spatial attraction emerges: sites from this phase tend to occupy different areas. From the Early to the Middle Bronze Age, spatial repulsion remains the dominant, though weak, signal, reinforcing the impression of shifting patterns of human presence. Interestingly, a weak signal of attraction re-emerges in the transition to the Late Bronze Age, suggesting that some places – or broader landscape zones – may have maintained their significance. The observed curve for the transition from the Late to the Final Bronze Age remains slightly above the expectation under spatial randomness. Trends of change between the Copper and Bronze Ages are also reflected in the plot referring to chronologically less determined contexts (i.e. *Copper Age nd* and *Bronze Age nd*), where the curve indicates spatial repulsion between the two datasets.

2. Radiocarbon dates as a proxy for demographic trends

The analyses described in the previous paragraphs highlighted both the potential and the limitations of the collected dataset, while also identifying some major shifts in the diachronic trajectory within the landscape. However, this study aims to go beyond the inherent limitations and static nature of a spatial dataset based merely on empirical archaeological evidence. The intention is to challenge the static nature of such data by integrating interpretive modelling approaches that allow us to explore hypothetical scenarios. In this context, radiocarbon dates were used to model demographic trends within the study area across the millennia under scrutiny, and to enable comparison within the broader context of the southern Italian peninsula.

Radiocarbon dates have become a valuable proxy for inferring demographic trends in prehistoric contexts, especially where direct evidence of population size is absent. By statistically analysing the distribution of calibrated radiocarbon dates through Summed Probability Distributions (SPD), it is possible to identify broad-scale fluctuations in human activity over time and compare them across spatial and cultural settings [4]. The DAD (Dates as Data) approach is based on the premise that the density of radiocarbon dates correlates with population size. This principle, however, has been widely criticised – both due to the uneven coverage across different chrono-geographical settings and because radiocarbon dates may derive from diverse anthropic contexts, as several authors have pointed out in recent studies [5].

Why, then, include this analysis in the present work? Because in this study the radiocarbon-based demographic reconstruction is contextualised within a broader framework of data collection and elaboration – from site distribution analysis to inductive modelling, and ultimately the topographic and ecological characterisation of exploited places. In this sense, it serves as an additional layer of support within a broader multi-proxy approach. If critically combined with other evidence, this analysis allows us to explore not only when shifts in occupation patterns occurred within the landscape (§ 1), but also whether they overlapped with broader demographic transformations.

For southeast Italy, I used the extensive AIDA database of Italian radiocarbon dates [6], extracting a dataset of 586 dates for the study area and 2067 dates for central-southern Italy as a whole (excluding Sicily and Sardinia). These were processed using the *rcarbon* R package [7], which facilitates normalisation and statistical modelling of radiocarbon distributions. The

[3] Nakoinz and Knitter 2016, p. 135.

[4] Palmisano *et alii* 2017, 2018, 2021a.

[5] Attenbrow and Hiscock 2015; Crema 2022.

[6] Palmisano *et alii* 2021b.

[7] Bevan *et alii* 2021.

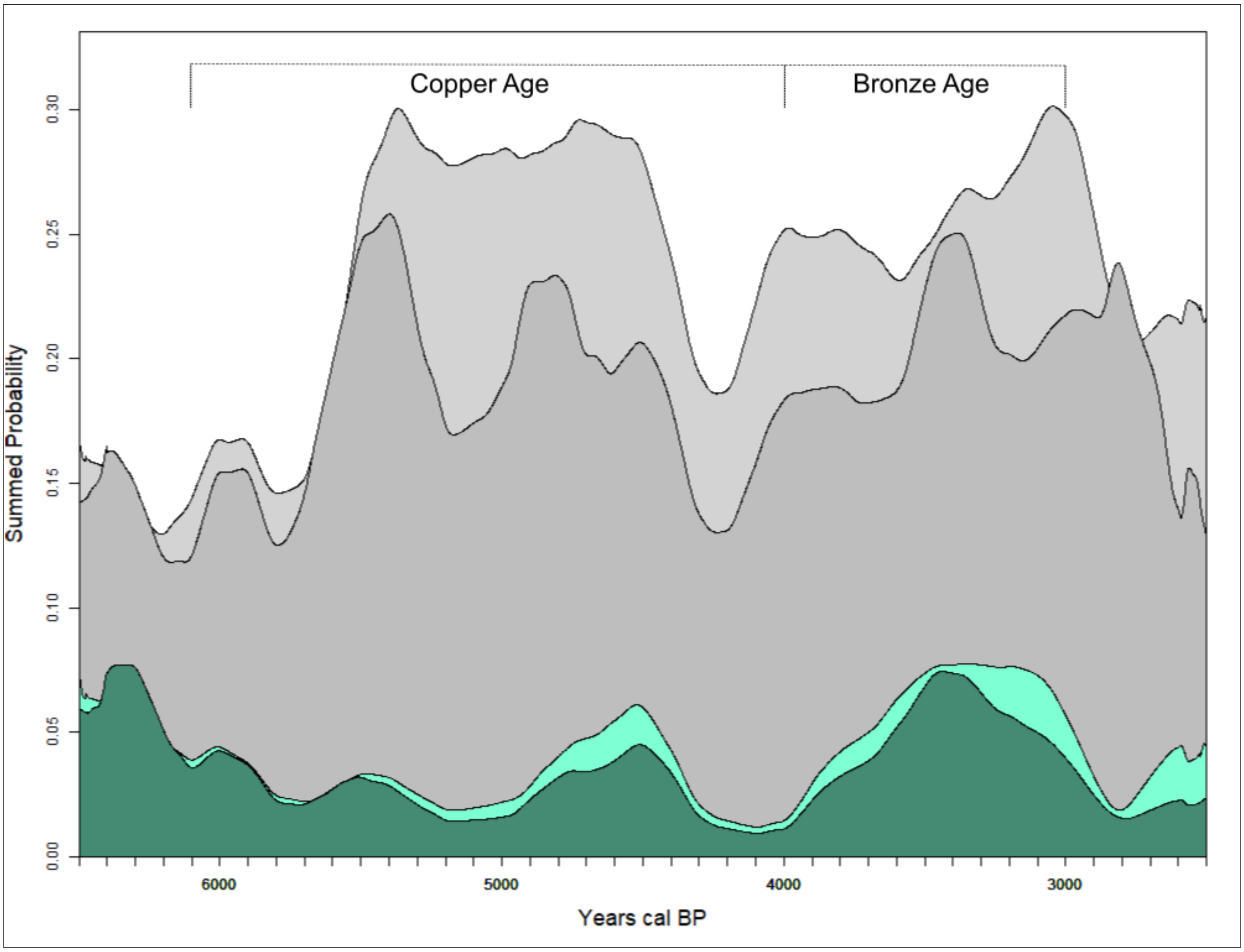

Fig. 6. - Summed Probability Distribution (SPD) of calibrated radiocarbon dates over time for central-southern Italy and the regions under scrutiny. The x-axis represents years before present (cal BP), ranging from 5500 to 2500 cal BP, while the y-axis represents the summed probability, reflecting the relative density of radiocarbon dates at different points in time. The grey areas depict the SPD for non-normalised (light grey) and normalised (dark grey) dates from central-southern Italy (n = 2067), while the green areas illustrate the SPD for non-normalised (light green) and normalised (dark green) dates from the regions under scrutiny (n = 586). Peaks in the graph reflect increasing trends in radiocarbon date frequency, potentially indicating phases of demographic expansion. Differences between the normalised and non-normalised distributions highlight variations in sample density and the effects of calibration over time.

dataset encompasses a wide range of contexts – including settlements, funerary sites, and caves – ensuring a demographically meaningful signal despite the heterogeneity of sources. This diversity is, on the one hand, necessary to construct a robust dataset: restricting the analysis to settlements alone would significantly reduce the sample size and limit the potential for meaningful demographic interpretation. On the other hand, it allows us to partially compensate for the uneven archaeological coverage across the study area, particularly in regions where domestic contexts are poorly known or scarcely investigated. Their inclusion represents a practical approach aligned with current best practices in radiocarbon-based modelling, aimed at charting broader demographic trends over time and space.

The plot (fig. 6) presents the outcomes of the Summed Probability Distribution (SPD). Trends in the curves may provide insights into phases of demographic expansion and decline. Overall, the curves relating to the entire dataset for central-southern Italy and those specific to the study area in south-east Italy show a good degree of correspondence, with the exception of the second half of the period between 6000 and 5000 cal BP. It is not straightforward to explain such a deviation – whether it reflects a genuine demographic trend or results from research bias. In my perspective, it is more likely attributable to research bias.

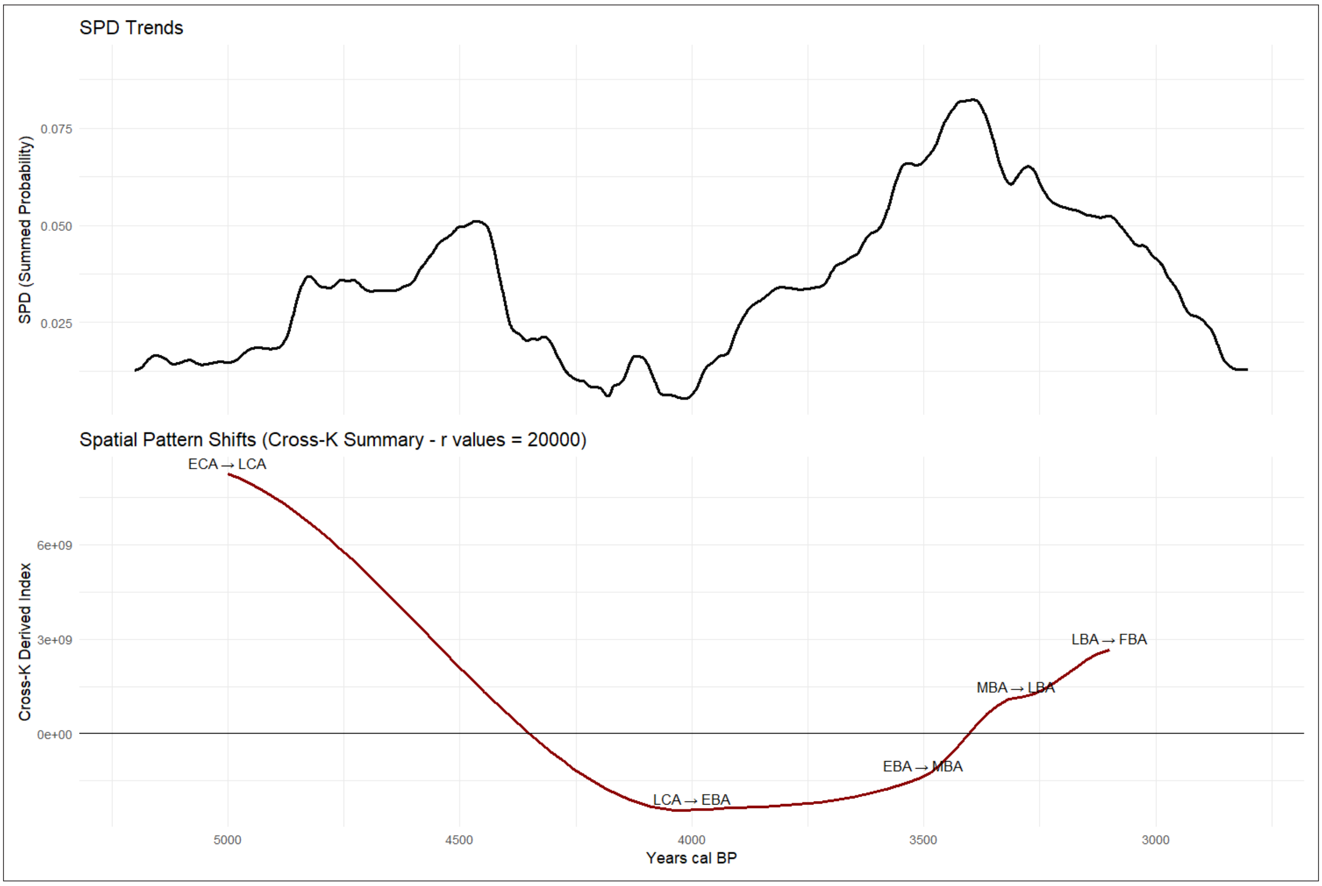

Fig. 7. - The upper panel presents the Summed Probability Distribution (SPD) of calibrated radiocarbon dates from the study area, used here as a proxy for demographic fluctuations. Peaks in the curve reflect phases of increased radiocarbon frequency, which may indicate episodes of population growth or intensified activity, while troughs may correspond to demographic contraction or reduced archaeological visibility. The lower panel displays a continuous summary of Cross-K results (r = 20 km), illustrating shifts in spatial interaction between successive chronological phases (i.e. ECA→LCA, LCA→EBA, EBA→MBA, MBA→LBA, LBA→FBA). The curve represents the deviation of the observed spatial association from expectations under random labelling. Positive values indicate stronger spatial continuity between phases (later sites occurring closer to earlier ones than expected), whereas negative values suggest spatial reorganisation or dispersion.

The Early Copper Age (ECA, 4th mill. BCE) is marked by a relatively modest signal, likely reflecting both lower population densities and preservation/research biases. A clearer increase is observed during the Late Copper Age (3rd mill. BCE). Nevertheless, a significant downturn is observed in the curve toward the end of the 3rd mill. BCE, possibly corresponding with the 4.2 ka BP climate event [8]. Conversely, the Bronze Age shows a marked increase of the curves. The Middle Bronze Age, in particular, corresponds to a peak in the SPD curve, suggesting a demographic expansion and/or more intensive and durable human occupation. This aligns well with archaeological indicators such as the emergence of long-lived settlements, including fortified sites, the intensification of land use across ecologically diverse zones, and the increasing visibility of social complexity. In contrast, the subsequent phases (Late Bronze Age and Final Bronze Age) display signs of contraction. However, the extent to which radiocarbon dates from the 1st mill. BCE affect the model, and their reliability in capturing demographic dynamics during this later phase, remains uncertain.

A visual comparison (fig. 7) between the outcomes of the cross-K function analysis and the normalised SPD trend for the study area offers a clearer perspective on broad-scale dynamics. In this plot, the values represented in the lower panel correspond to a 'Cross-K Derived Index', calculated as the difference between the observed K-function and the mean of the simulated envelopes at a distance of 20 km. This method offers a simplified yet informative summary of spatial interaction between site distributions across successive chronological phases, as shown in the cross K function plots (fig. 6). Positive values indicate greater-than-expected spatial association (i.e. clustering), whereas negative values point to spatial separation or reorganisation. In simpler terms, positive values indicate that the contexts under examination are spatially located in the same areas as those of the previous phase, whereas negative values reflect a shift in their spatial positioning.

[8] Bini *et alii* 2019; Di Rita and Magri 2019; McKay *et alii* 2024.

The SPD decline observed in the late 3rd mill. BCE, followed by a subsequent increase, is consistent with transformation patterns in site distribution highlighted by the cross-K results. These transitions are especially evident in the shift from the Late Copper Age to the Early Bronze Age (LCA → EBA), marked by a negative Cross-K Derived Index, and in the shift from the Early to the Middle Bronze Age (EBA → MBA).

3. Landscape characterisation based on morpho-hydrological units

Having examined the macro-temporal shifts in settlement patterns across the study area, it is now crucial to assess their qualitative dimension – in particular, the topographic and ecological contexts in which these transformations occurred. Before addressing where people chose to live, however, an objective picture of the types of landscape available was required. By clustering terrain and hydrological variables into discrete ecological units, I produced a background map that is independent of archaeological visibility or modern administrative boundaries. Thus, in this section I outlines this analytical process.

Topographic characterisation was carried out using the data presented in the previous chapter (§2 - Tab. 2). The approach follows that adopted in a recently published study presenting the first outcomes of this project, albeit with some adjustments (Lucci 2025). In particular, the criteria used to define coastal, subcoastal, and inland case studies were revised. These classifications are based on cost-surface analysis, which led to a redefinition of the morpho-hydrological units.

For each site, values of the different parameters were extracted and normalised to ensure comparability across datasets. All values were rescaled within

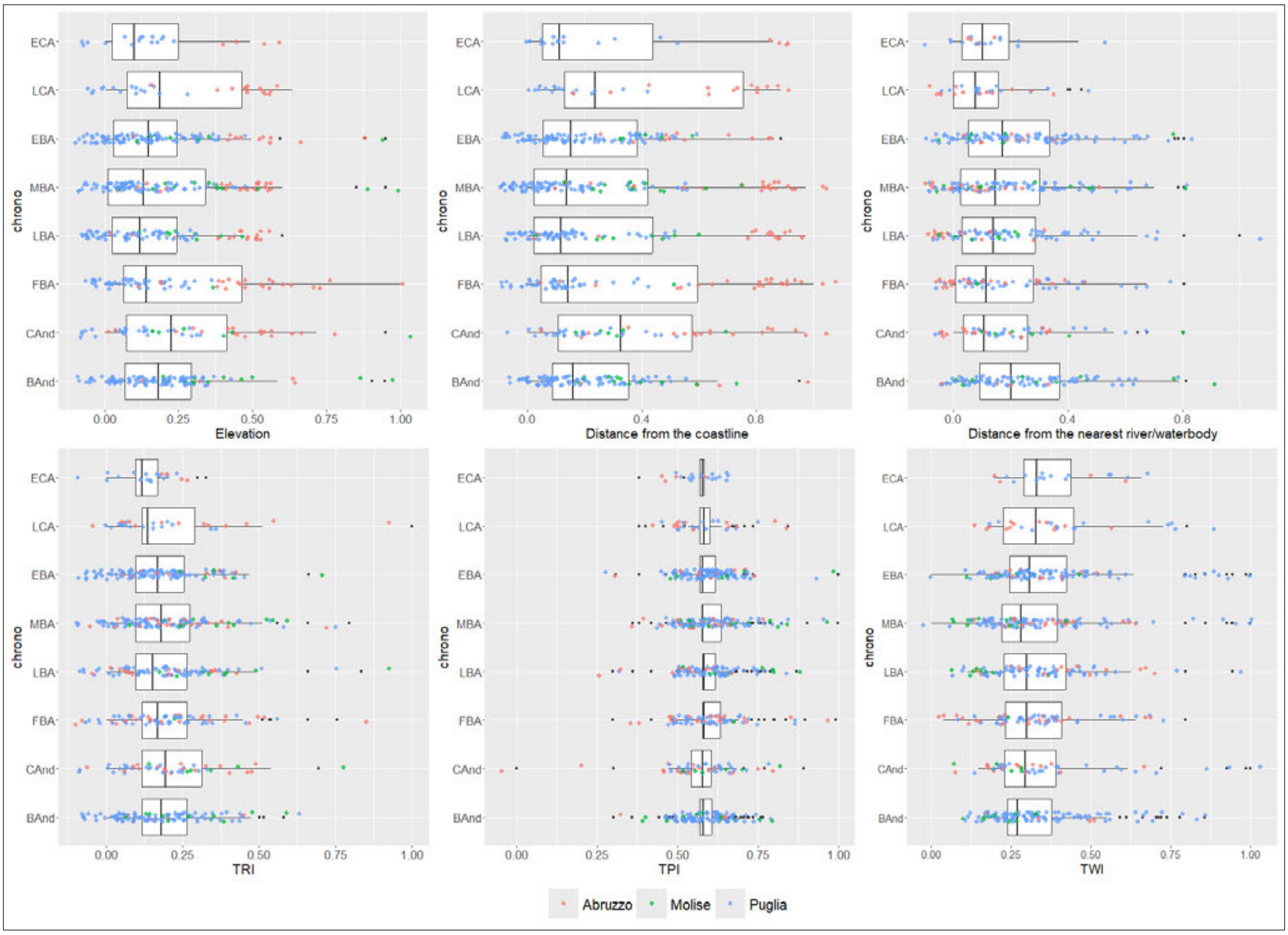

Fig. 8. - Boxplots and jitter points representing normalized values for each environmental variable analysed in the topographic characterization of the case studies. The variables include elevation, distance from the coastline, distance from the nearest river or waterbody, topographic roughness index (TRI), topographic position index (TPI), and topographic wetness index (TWI). Each point represents a site from one of three regions: Abruzzo (red), Molise (green), and Puglia (blue). The boxplots show the distribution and spread of data within each chronological phase, while the jitter points illustrate individual site values, helping to visualize both the central tendency and variability of variables across different times and regions.

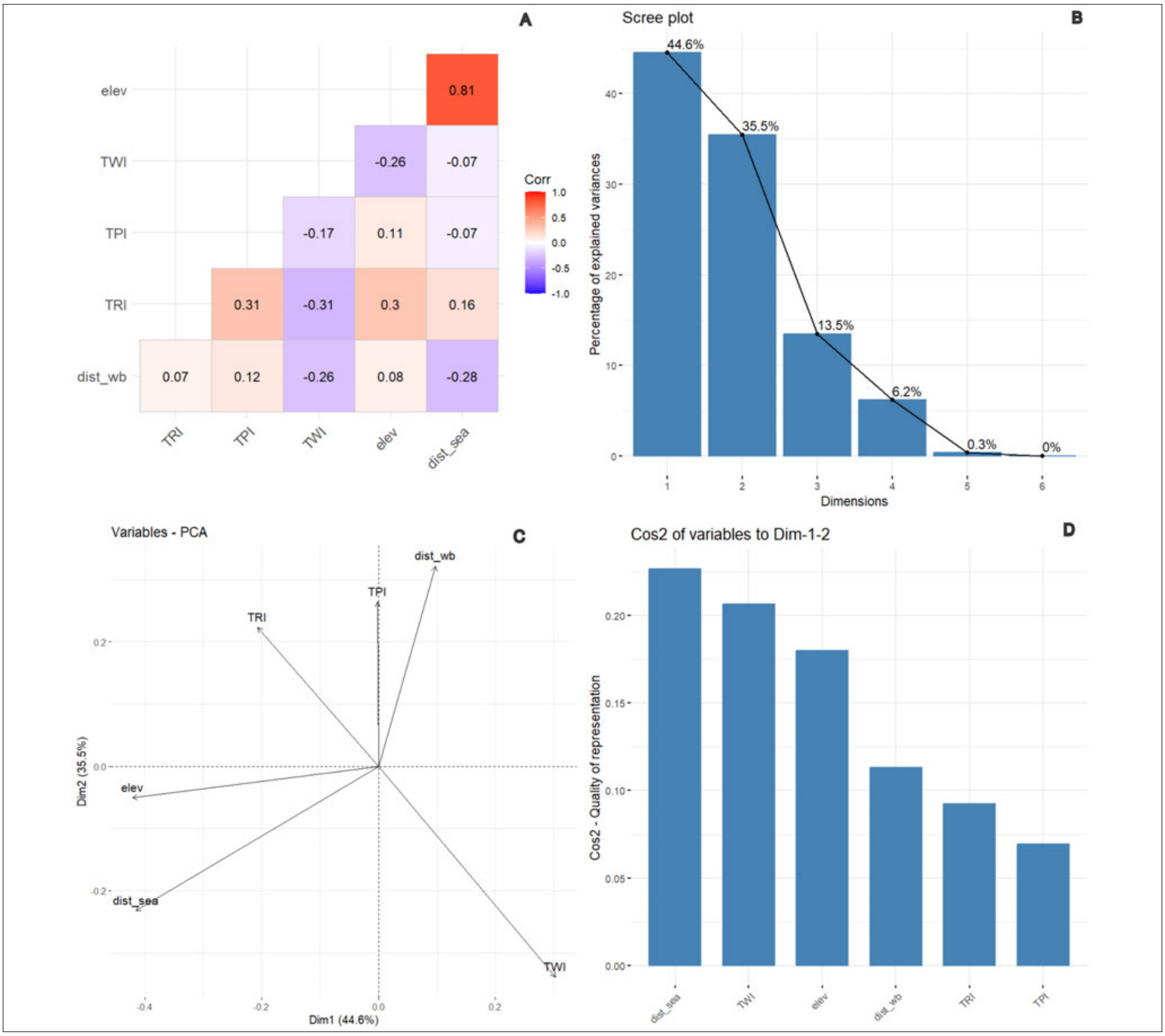

Fig. 9. - PCA analysis of the environmental variables; A) Correlation matrix of topographic and environmental variables used in the analysis. The figure shows the Pearson correlation coefficients between six key variables. The correlation coefficients range from -1 (indicating a strong negative correlation) to 1 (indicating a strong positive correlation), with values close to 0 suggesting no correlation; B) Scree plot of the components, the first two components are considered the most significant; C) Biplot showing impact of each attribute on the principal components; D) Plot showing how much each variable is represented on the principal components 1 and 2.

a 0-1 range, and indices such as TPI, TRI, and TWI underwent square-root transformations to compress extreme values and mitigate distribution distortions – an approach widely applied in landscape analysis[9]. Results were plotted using box plots and jittered points (fig. 8). While some trends can be observed in these plots, formalising those with greater informational value allows us to better exploit the potential of the data. For this purpose, a Principal Component Analysis (PCA) was conducted [10]. Normalising the data before PCA ensured that no single variable disproportionately influenced the results[11]. The correlation matrix (fig. 9A) highlights expected positive relationships among landform attributes (elevation, TRI, and TPI), also reflected in the biplot (fig. 9B). These relationships confirm the mutual reinforcement of these parameters in distinguishing between lowland,

[9] Spencer and Bevan 2018.

[10] Carlson 2017, p. 265.

[11] *Ibidem*, p. 269.

Variables	Classes	Breakpoints (v = Value)
Distance to the coastline	Inland	$v > 4h$
	Subcoastal	$2h < v < 4h$
	Coastal	$v < 2h$
Elevation	Lowlands	$v < 100$ m a.s.l.
	Uplands	100 m a.s.l. $< v <$ 500 m a.s.l.
	Highlands	500 m a.s.l. $< v <$ 1000 m a.s.l.
	Mountains	$v >$ 1000 m a.s.l.
TWI	Drylands	$v < -3.631779$
	Transitional zone	$-3.631779 < v < 3.468444$
	Moderately Wet areas	$3.468444 < v < 19.859759$
	Wetlands	$v > 19.859759$

Table 2. - Classification scheme of the topographic/environmental variables used for defining the diverse ecological units (v=value).

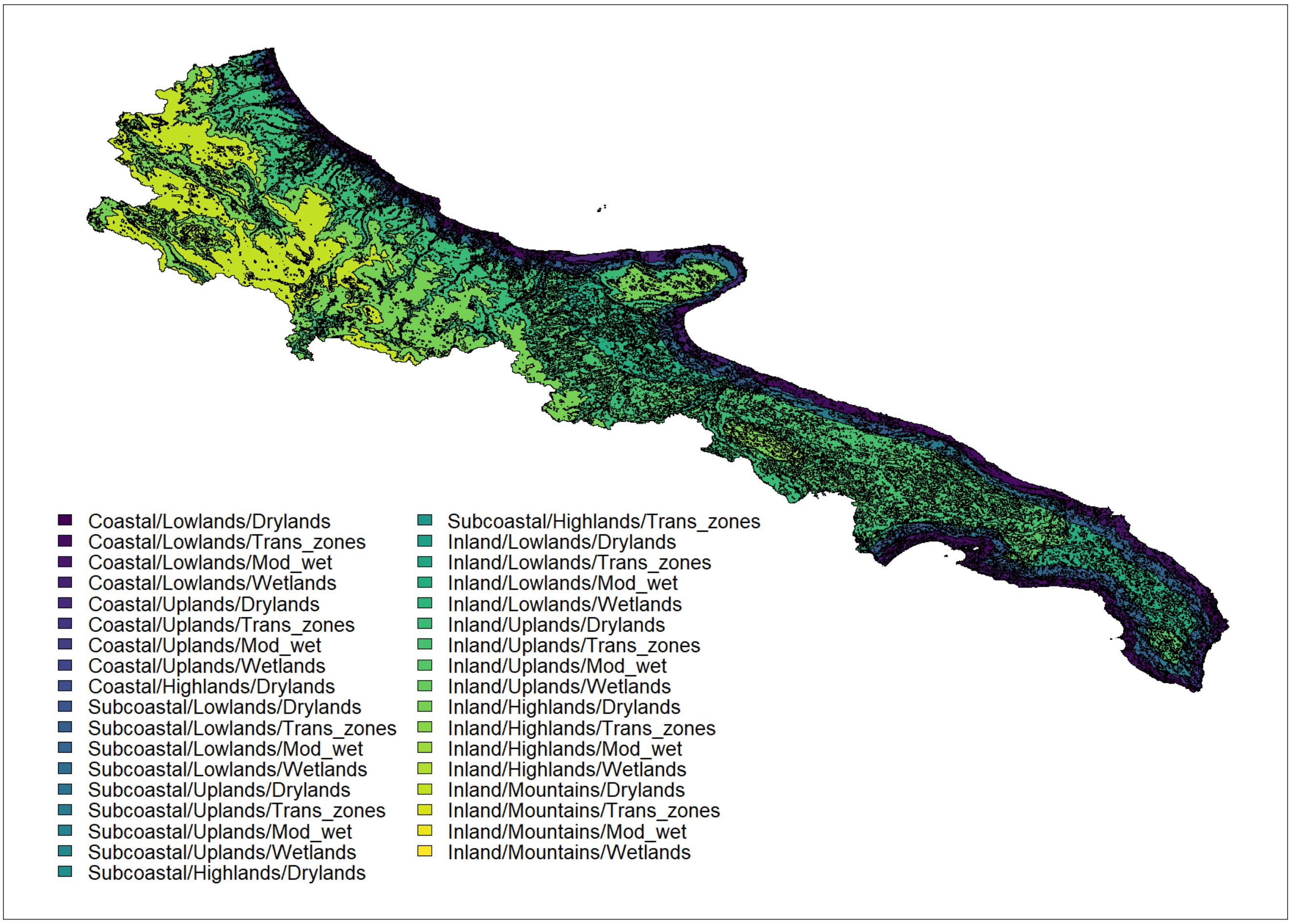

Fig. 10. - Map of the 35 morpho-hydrological units classified by combining elevation, Topographic Wetness Index (TWI), and cost-surface-based distance from the current coastline.

upland, and mountainous settings. Conversely, the Topographic Wetness Index (TWI) shows a moderate negative correlation with elevation and TRI, consistent with the fact that higher, more rugged areas tend to be less moisture-retentive. The variables related to distance from the coastline and inland water bodies display weaker correlations with topographic indices, suggesting that proximity to water sources was not directly conditioned by elevation or terrain morphology, but may reflect different interaction dynamics with the landscape. Clearly, elevation and distance from the sea are highly correlated, reflecting the morphology of the southern Italian peninsula, where the Apennine range forms its central backbone.

In summary, the matrix suggests that some variables are closely interrelated and reflect shared geomorphological characteristics, while others – though less correlated – contribute independent and complementary dimensions that enrich our understanding of

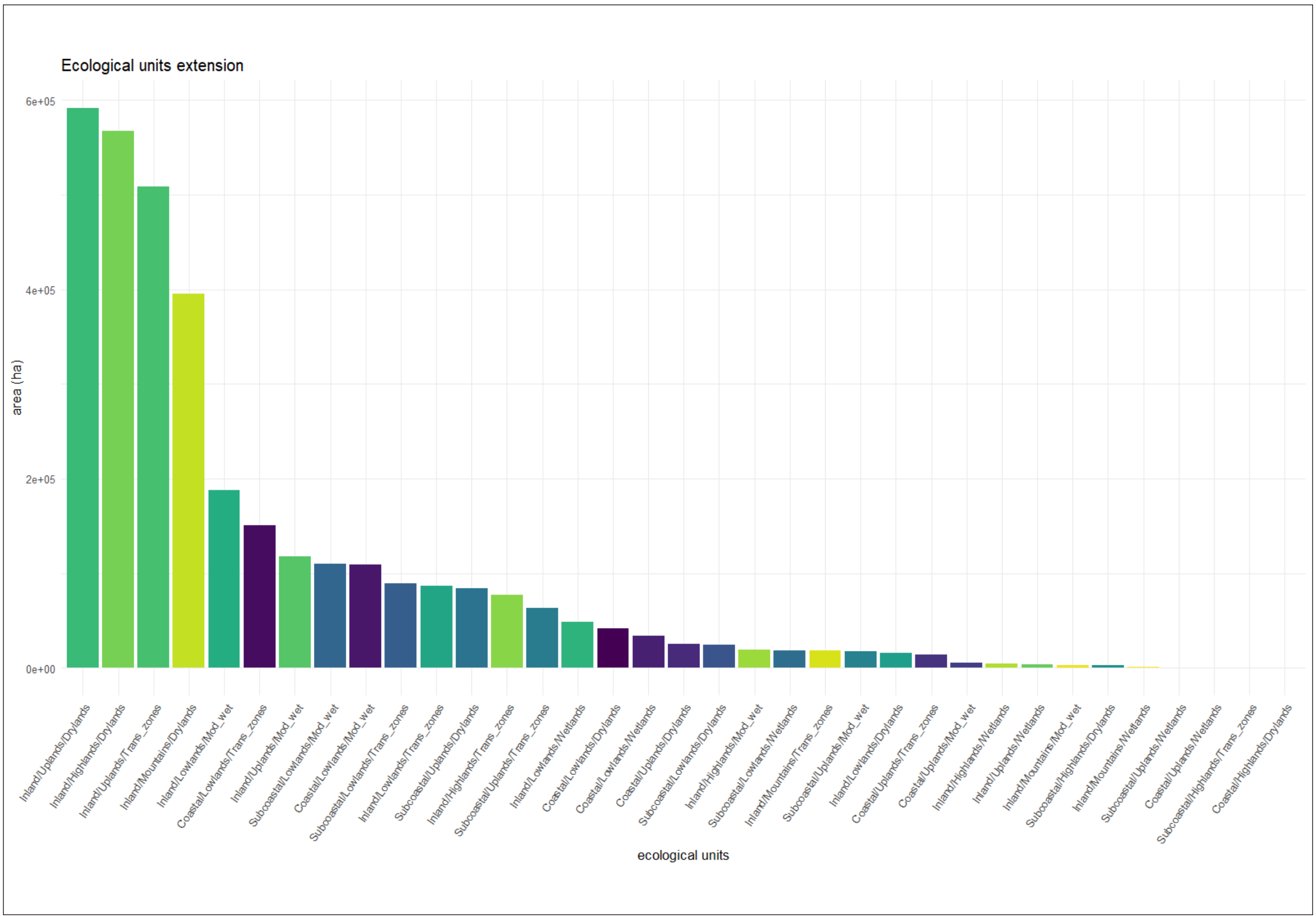

Fig. 11. - Surface extension (in ha) of each ecological unit within the study area.

the ecological settings associated with human occupation.

The two principal components explain approximately 80% of the variability in site distribution (fig. 8), with distance from the coastline and TWI emerging as the most influential factors, followed by other topographic attributes (fig. 9C).

The three most significant continuous variables (fig. 9D) were further categorised (Tab. 2) and combined to define distinct morpho-hydrological units.

Units located along the present-day shoreline or within two hours of walking distance were classified as coastal; those situated between two and four walking hours were defined as subcoastal; while sites located beyond four walking hours were assigned to the inland category. Elevation classes were heuristically determined based on the study area's altitudinal range, while distance to the coastline was classified using a walking speed of 1.5 m/s on hilly terrain [12]. TWI values were segmented into four theoretical categories using K-means clustering in R.

Finally, the classified data were combined to define territorial units – here termed morpho-hydrological units – integrating topographic features with indicators of moisture and hydrology. The map illustrates the 35 resulting morpho-hydrological units [13] (fig. 10), each defined by a unique combination of elevation, Topographic Wetness Index (TWI), and cost-surface-based distance from the present-day coastline. For instance, a unit labelled as "Coastal / Lowlands /Wetlands" refers to areas within two hours of walking distance from the sea, characterised by low elevation and high surface moisture, including zones with the presence of waterbodies. The classification integrates geomorphological and hydrological

[12] Tobler 1993.

[13] The outcome partially differs from previously published results due to the adoption of a new technique for defining coastal, subcoastal, and inland contexts, based on cost-surface analysis (Lucci 2025).

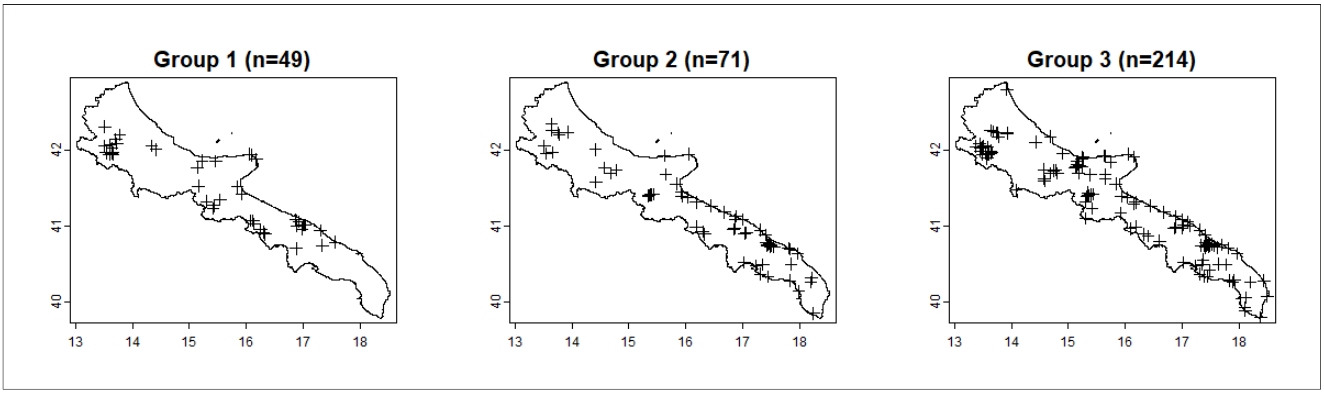

Fig. 12. - Analysed datasets referring to the different phases under scrutiny. Each dataset is composed of sites classified as settlements, along with a random 50% sample of sites that are not unequivocally settlements but could nonetheless attest to human activity presence. Moreover, only those sites that could be placed within specific chrono-cultural phases were selected.

parameters to produce discrete landscape units that serve as the analytical framework for assessing human-environment interactions across the study area.

The plot (fig. 11) illustrates the total surface area covered by each of the 35 morpho-hydrological units identified in the study area. The units are unevenly distributed, with a clear dominance of certain environmental configurations over others. For example, inland units characterised by low to moderate TWI values and higher elevation cover large portions of the study region. In contrast, coastal and subcoastal units occupy a more restricted area.

4. MaxEnt modelling: predicting suitable places for permanent settlements

MaxEnt serves a dual purpose: it quantifies the relative influence of each environmental raster layer on a phenomenon and produces suitability maps indicating areas of higher or lower probability of occurrence. Yet understanding what defines those suitable places is a different question. By integrating detailed landscape characterisation with MaxEnt outputs, we can infer not only where a location was suitable for a human community, but also why it was so.

For each chronological phase a suitability surface – showing, cell by cell, how suitable an area was for occupation – was draped over that ecological backdrop.

This section describes the construction, evaluation, and application of the MaxEnt models used to identify areas of south-eastern Italy that were potentially suitable for long-term settlement during the Copper and Bronze Ages. Here the landscape is no longer classified a priori on purely physical grounds; instead, its suitability is inferred directly from the distribution of the archaeological evidence, thus results are inductive models [14].

The presence-only dataset includes every site classified as a settlement, plus a random 50% sample [15] of sites that are not unequivocally residential but nonetheless could indicate human activity (e.g. seasonal or task-specific locales). Including this controlled slice of "probable-use" sites prevents the dataset from becoming so sparse that the MaxEnt algorithm returns unstable predictions, yet keeps the focus on the conditions required for permanent settlement. Moreover, only those sites that could be placed within specific chrono-cultural phases were processed, excluding those attributable only generically to the Copper or Bronze Age.

To link the modelling results to the broad occupational and demographic shifts outlined earlier (fig. 7), and to reduce the effects of chronological uncertainty while preserving meaningful temporal resolution, the dataset was further aggregated into three broad chronological macro-phases. This level of temporal aggregation reflects both the uneven distribution of archaeological evidence across periods and the need to maximise the number of observations available for inductive modelling.

Accordingly, three chronological macro-phases were defined [16]:

[14] An inductive model is any model that learns general rules or regularities from specific observations, then uses those learned regularities to make predictions about new, unseen cases (Nakoinz and Knitter 2016, p. 23).

[15] This value was determined through several attempts using both lower and higher thresholds. Lower values negatively affected the statistical reliability of the models (AUC for both training and test), while higher values excessively reduced the weight of stable settlements in the modelling process.

[16] This approach excluded sites that were not attributable to a

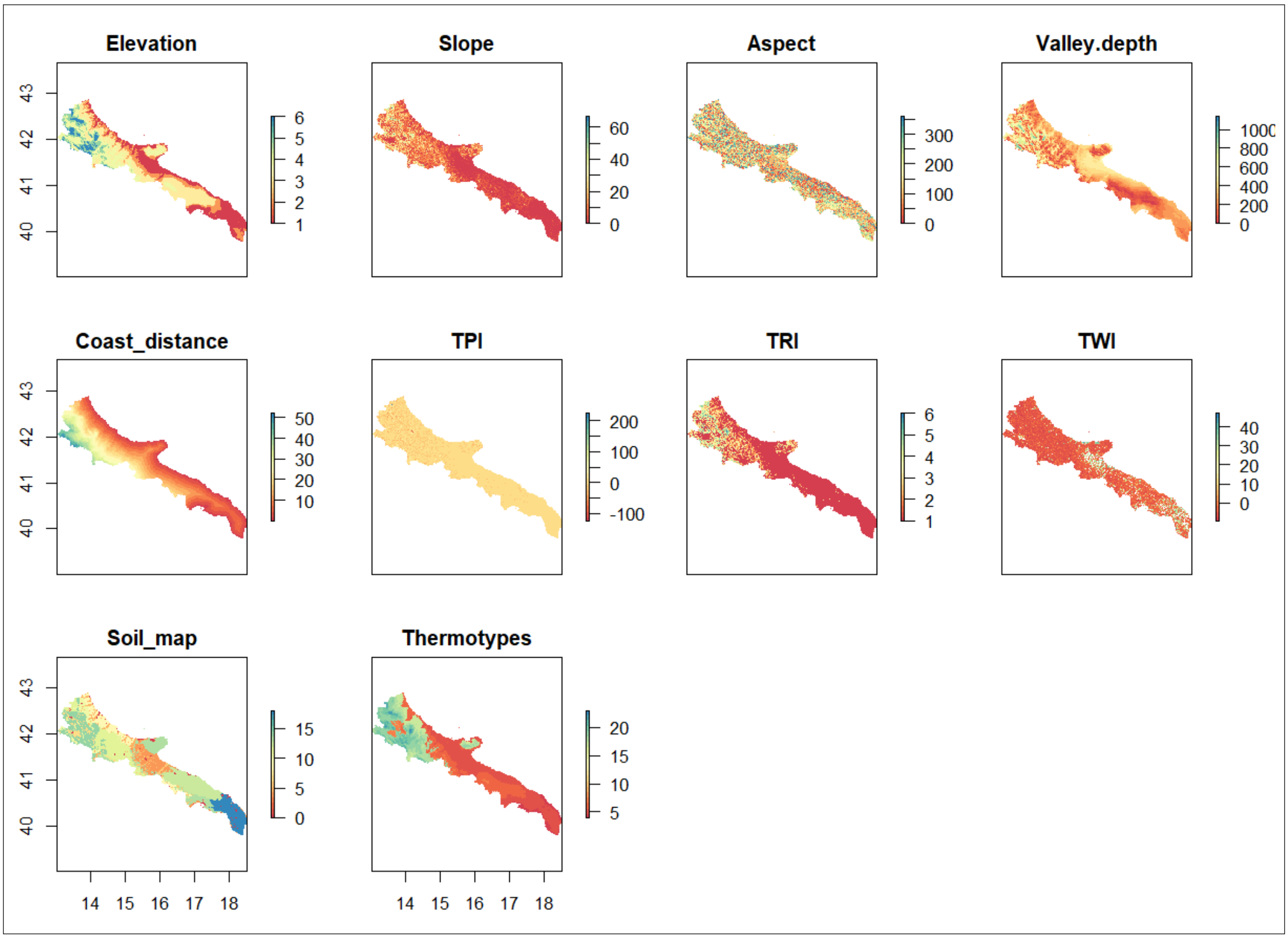

Fig. 13. - Processed environmental features in the form of raster-grids.

- Phase 1 - 4th and 3rd millennia BCE [17];
- Phase 2 - 20th to 16th centuries BCE;
- Phase 3 - 15th to 11th centuries BCE.

As already noted in §4.1, the datasets differ markedly in the number of sites represented (fig. 12), notably the low number of Phase 1 case studies, which must be considered when assessing the reliability of the resulting MaxEnt model.

For the construction of morpho-hydrological units, only terrain descriptors were retained, as these variables exhibit relatively low rates of change at the scale of analysis over the mid- to late Holocene: elevation, TRI, TPI, TWI, distance to the present coastline and distance to inland watercourses. Together these six layers capture relief, surface hydrology and proximity to marine or fluvial resources – sufficient to partition the study area into *morpho-hydrological units* that remain comparable from the fourth to the first mill. BCE.

For the phase-specific MaxEnt modelling a different stack was required (fig. 13). I used selected and partially different morpho-hydrological-edaphic features – elevation, slope, aspect, valley-depth, TWI and the soil map – and supplemented them with thermotypes from the work of Pesaresi and colleagues [18]. These predictors were chosen to achieve a compromise between keeping the model lean (so that it does not overfit) and still describing the full range of environmental constraints. The five terrain-derived layers (elevation, slope, valley depth, soil class and topographic wetness) represent features that change little over millennia; they encapsulate the long-term advantages of a place – good drainage on a spur, deep

specific phase of the Copper and/or Bronze Ages.

[17] Ten sites attributed to the Palma Campania culture are included in this group, because the horizon spans the late 3rd to early 2nd millennia BCE.

[18] Pesaresi *et alii* 2014.

alluvial soils on a flood-plain, natural shelter in an incised valley. To complement these relatively stable variables, this study integrates a climatic dimension through thermotypes – categorical zones derived from the Worldwide Bioclimatic Classification System. These reflect the average thermal conditions of an area, including seasonal temperature patterns and thresholds of biological activity. Unlike continuous climatic rasters, thermotypes provide an interpretable synthesis of long-term climatic dynamics that can affect land-use options and seasonal rhythms of occupation. Variations in thermotype zones – such as shifts between Supra, Meso, and Thermomediterranean belts – can help identify areas that were more or less suitable for cultivation, pastoralism, or year-round habitation, adding a vital ecological layer to the understanding of ancient communities' choices in engaging with the landscape.

4.1. *Exploring MaxEnt outputs*

Separate MaxEnt runs were generated for each macro-phase. The resulting suitability surfaces – presented as heat-maps – highlight those landscapes where stable communities could plausibly have emerged at each stage of the analysed chronological phase. MaxEnt models were run using five-fold cross-validation. The full set of MaxEnt outputs – HTML summaries, responsecurve data – can be inspected and downloaded from the project's open repository – https://enricolucci.github.io/MODLAND-R-code-for-MaxEnt.

We will proceed in two steps: (i) analysing model performance by examining the crossvalidation outputs, and (ii) using that information to understand the presence in the diverse ecological units.

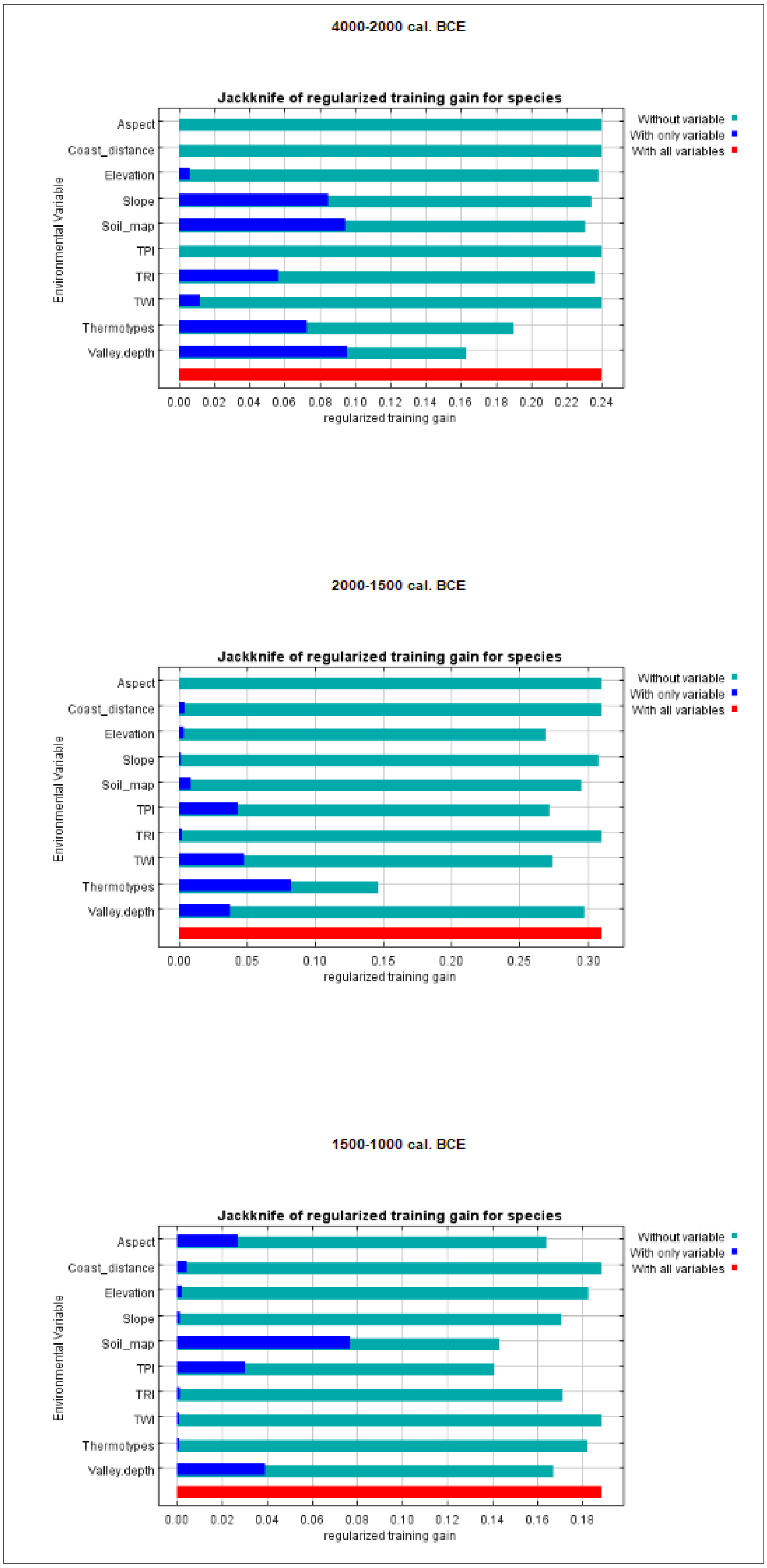

Fig. 14. - Results of the jackknife test assessing variables importance based on cross-validation outputs.

Variables importance in cross-validation outputs
Phase 1 (4000-2000 cal BCE)

The average test AUC = 0.712 ± 0.080 (5fold CV), indicating a model with reasonable predictive skill. The relatively contained standard deviation suggests stable performance across folds, pointing to a reasonably consistent spatial pattern despite potential sample limitations.

The jack-knife analysis (fig. 14) reveals that settlement choices during this period could have been influenced by a combination of ecological variables, with soils and thermotypes emerging as the two most informative predictors. Soils contributes the most when used alone. Meanwhile, thermotypes cause the sharpest drop in model gain when omitted and shows the highest permutation importance, indicating that temperature zones contributed unique and non-redundant information, likely reflecting a preference for specific areas (buffered from seasonal extremes?).

Valley depth also plays a significant role, reflecting the attractiveness of deeply incised zones that combine access to water, likely fertile soils, and possible mobility routes. Other topographic features such as slope and ruggedness (TRI) contribute more modestly but still suggest an interest in heterogeneous terrain, furnishing diversified environmental conditions.

Overall, the results point to a preference for micro-regional niches. This pattern supports the idea that communities in this phase could have selected settlement areas that balanced environmental affordances with the need for resource diversity and mobility.

Phase 2 (2000-1500 cal. BCE)

The average test AUC = 0.763 ± 0.099 (5fold CV), marking the highest performance among the models so far. This result falls squarely within the “moderate skill” range and shows good consistency across folds. With a 26.3 % gain over the random baseline, the model captures a robust signal, though – like all other models – its outputs are best interpreted as general suitability trends rather than precise predictors of site locations.

The jack-knife test (fig. 14) highlights thermotypes as the single most informative variable. It provides both the highest gain when used in isolation and the steepest drop in gain when omitted, with a contribution of 41.6 % and a permutation importance of 41.2 %. This suggests that climatic envelopes – likely structured along altitudinal gradients – could have played a significant role in structuring site location, notably for the northern part of the study area, where occupation chiefly interested inland plains and intramontane valleys. However, because thermotypes and elevation are correlated, care is needed in interpretation: thermotypes may be acting as a proxy for broad bioclimatic zones rather than temperature per se.

Elevation remains highly relevant (29 % permutation importance), supporting the idea that settlements spanned a wide altitudinal range. Notably, while mountainous areas may have been avoided, both lowlands and uplands were strategically used – an aspect that will be explored contextually in the following chapter.

Topographic variables such as TPI (14.7 %) and TWI (18.2 %) also carry weight. TPI points to a preference for sites in intermediate or dominant micro-relief positions, possibly connected to visibility or meaningful places – e.g. reference points for movement. TWI’s role may reflect a tendency to locate settlements taking into account soil wetness or water availability.

Valley depth (7.4 %), Soil_map (3.8 %), and Slope (1.3 %) offer supporting signals, while TRI, Coast distance, and Aspect are essentially irrelevant in this model. Together, the results portray Phase 2 settlement patterns as shaped by a complex mix of climatic, altitudinal, and topographic variables – with less emphasis on soils and coastlines than in other periods.

Phase 3 (1500 - 1000 cal. BCE)

The average test AUC = 0.641 ± 0.064 (5-fold CV), placing the model at the lower end of moderate predictive skill. While it performs meaningfully above the random baseline, its limited discriminatory strength requires a careful, heuristic reading of the resulting map. Nonetheless, the low standard deviation across folds indicates internally stable results.

The jack-knife test (fig. 14) shows Soil_map as the variable with the highest gain when used in isolation (41.9 % contribution). However, its omission does not produce the sharpest drop in gain, nor does it rank highest in permutation importance (30.9 %). This suggests that while Soil_map provides valuable structure to the model, its influence may reflect broader topographic patterns embedded in the soil classification – such as valley systems or slopes – rather than direct selection for specific soil properties.

By contrast, TPI (20.9 % contribution; 20.6 % permutation importance) stands out as the most uniquely informative variable: its removal causes the largest drop in gain, underscoring a strong preference for locally elevated or shoulder positions. This signal is

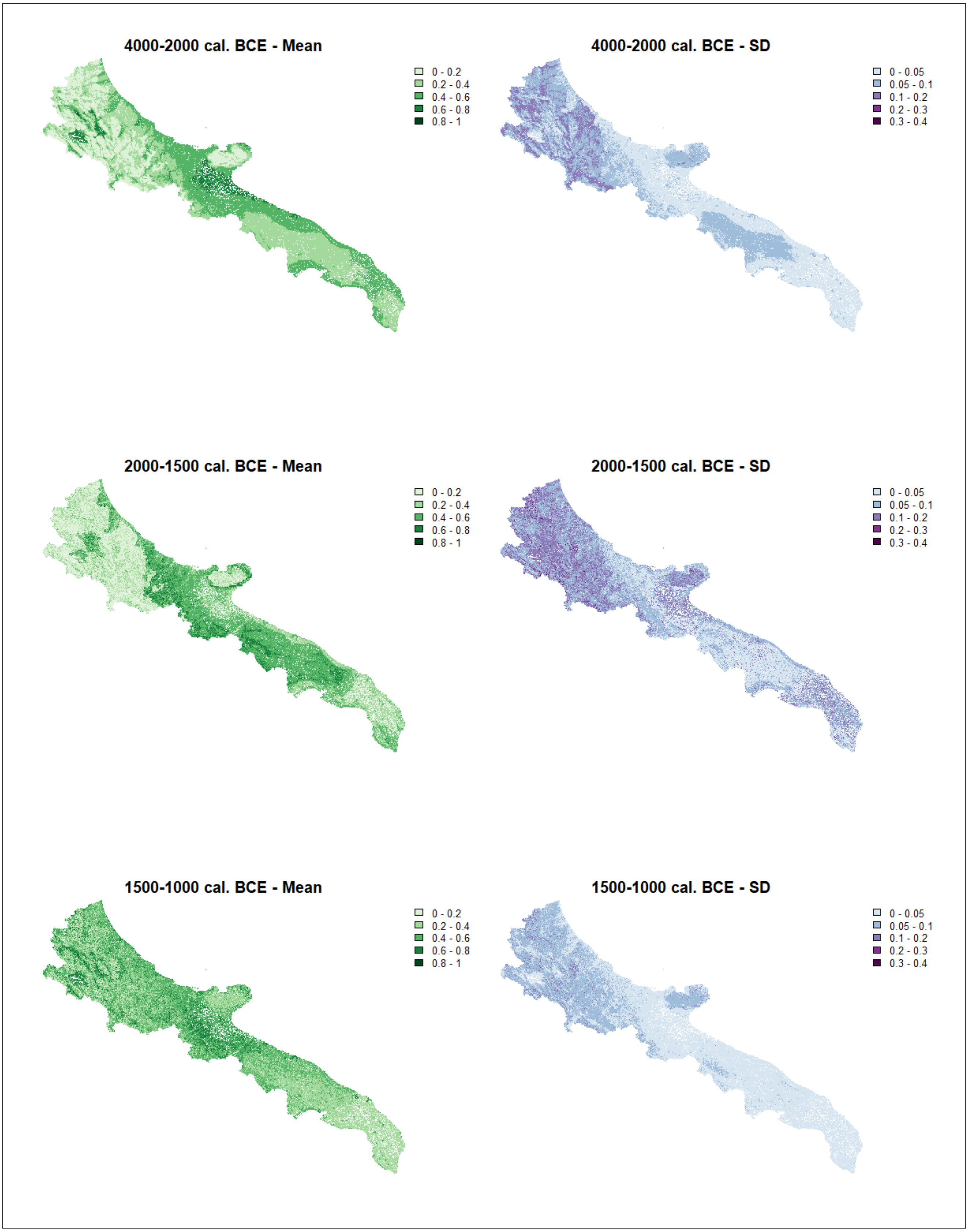

Fig. 15. - Suitability and model-uncertainty maps for the three chronological phases. For each row the panel on the left displays the mean suitability surface obtained by averaging the five cross-validation folds, while the panel on the right shows the corresponding per-pixel standard deviation. Darker purple tones mark areas where the folds disagree most strongly, signalling greater predictive uncertainty.

consistent with the emergence of settlement traditions linked to defensive advantage, visibility, or meaningful prominence during this phase.

Additional topographic variables – including Aspect (13.2 %), Slope (5.5 % / 16.9 %), and Valley depth (7.6 % / 11.8 %) – contribute meaningfully to the model. In particular, the modest impact of Aspect may relate to micro-climatic or exposure preferences, although its low permutation importance suggests this effect is context-dependent or collinear.

In contrast, Elevation, Thermotypes, TWI, and Coast distance play marginal roles, indicating that broader altitudinal and climatic parameters were less decisive than in earlier phases.

Overall, Phase 3 settlement choices appear to have been structured around micro-topographic dominance and terrain visibility, rather than broad environmental gradients. The apparent influence of soil types is likely entwined with these same landform dynamics. As such, the model highlights a consolidation of settlement strategies rooted in local prominence and strategic positioning, albeit within a predictive framework of modest strength.

4.2. *MaxEnt suitability maps from cross-validation*

For each chronological phase, the five MaxEnt cross-validation folds were collapsed into summary rasters comprising a mean suitability surface and a corresponding per-pixel standard deviation map (fig. 15). The mean maps represent the average predicted probability of suitability at each cell across the five model replicates, while the standard deviation surfaces quantify the degree of internal variability. This approach retains the full presence signal across all five folds by combining their predictions into a single surface, thereby smoothing out random variation, suppressing fold-specific noise, and providing a spatially explicit visualisation of model uncertainty through the accompanying standard deviation map.

The mean suitability maps (fig. 15, left column) show the model's estimate of landscape suitability for each chronological phase, with values ranging from white (low suitability, ≤ 0.10) to dark green (high suitability, ≥ 0.80). Light tones mark areas where stable settlement is unlikely, while medium to dark green shades highlight zones considered increasingly favourable. It is crucial to stress that these maps express relative probabilities rather than absolute predictions. A green cell in one phase signals areas that, according to the phase-specific model and training data, offer the most suitable conditions for settlement. However, this does not imply that settlements actually occurred there.

The standard deviation maps (fig. 15, right column) function as visual indicators of model uncertainty. During statistical modelling, they act as pixel-level weights, reducing the influence of areas with high variability across folds. In visual terms, they alert the reader to regions where the interpretation of high suitability should be treated cautiously. For example, in the 2000-1500 cal BCE slice, some of the lowest suitability signals – notably in the northern mountainous areas – coincide with the darkest purple tones in the SD map, indicating substantial fold-to-fold variation, thus the models for that zone must be carefully interpreted. While not uniform, this pattern of spatial overlap between high suitability and high uncertainty warrants careful interpretation.

But what can these models actually tell us at this stage of the analysis? Perhaps not very much, yet some general tendencies can nevertheless be cautiously identified. Broadly speaking, they suggest a potential trend towards a wider and more diversified human impact on the landscape over time. In particular, the third-phase model shows a more extensive distribution of suitable areas, including zones characterised by rugged or mountainous terrain. This may reflect a broader ecological engagement by human groups, or simply the model's improved sensitivity to local-scale variation. Indeed, the final map presents a wider spread of moderate-to-high suitability – depicted in green tones – alongside a more nuanced gradient of values across space. This internal diversification could indicate increasingly complex patterns of land use, or be a result of the model's greater ability to capture fine-grained environmental differences [19]. Some areas appear consistently suitable across all phases, pointing to long-term ecological stability or sustained human interest. Others emerge only in the final phase, possibly signalling shifts in mobility, resource targeting, or landscape accessibility.

5. Integration of phase-specific MaxEnt outputs with morpho-hydrological and thermotype maps

So far, we have visualised a quantitative classification of the study area, but it is now time to qualify suitable and non-suitable zones by overlaying the

[19] Taking into account that models result from a larger dataset (see fig. 12).

MaxEnt models with morpho-hydrological and thermotype maps.

The Sankey diagrams (fig. 16) illustrate how zones of predicted suitability are distributed across the morpho-hydrological units (fig. 10). Sankey diagrams visualise how quantities are distributed or flow between categories, using bands whose thickness is proportional to the value they represent. Nodes (categories) are placed sequentially, often left to right, and flows link them to highlight dominant or marginal pathways. It is important to remember that these diagrams reflect outputs from inductive suitability models rather than actual distributions; they should therefore be interpreted as representations of potentially exploitable ecological niches, and must be read in combination with the suitability maps discussed above (fig. 15).

Phase 1(4000-2000 cal BCE). The diagram reveals a relatively balanced distribution of suitable areas across the coastal, subcoastal, and inland zones, with a certain predominance of inland flows. Most of the suitability is channelled through lowlands and uplands, which act as key morphological units. In contrast, highlands and mountainous zones show only limited flows, indicating a lower potential for exploitation in these terrains during this phase. On the hydrological side, suitability is fairly evenly distributed across drylands, transitional zones, moderately wet areas, and wetlands, with no single category clearly dominating. This pattern points to a flexible relationship with diverse environmental settings, particularly ecotonal or marginal environments that offered varied resource opportunities. Overall, the model suggests that during the Copper Age period, human groups potentially exploited a broad spectrum of landscape niches without strong preference for specific hydrological conditions. This diffuse suitability may reflect highly flexible settlement strategies, with communities exploiting a wide range of ecological niches.

Phase 2 (2000-1500 cal BCE). The modelled suitability indicates a growing role for coastal areas, which show a more prominent contribution compared to the previous phase – particularly through connections with lowlands and uplands. While subcoastal and notably inland sectors remain important, the increased weight of coastal flows may reflect shifting patterns of settlement – such as the emergence of long-lasting fortified centres – and changing resource use, possibly linked to access routes, alluvial plains, or maritime exploitation. The lowlands and uplands

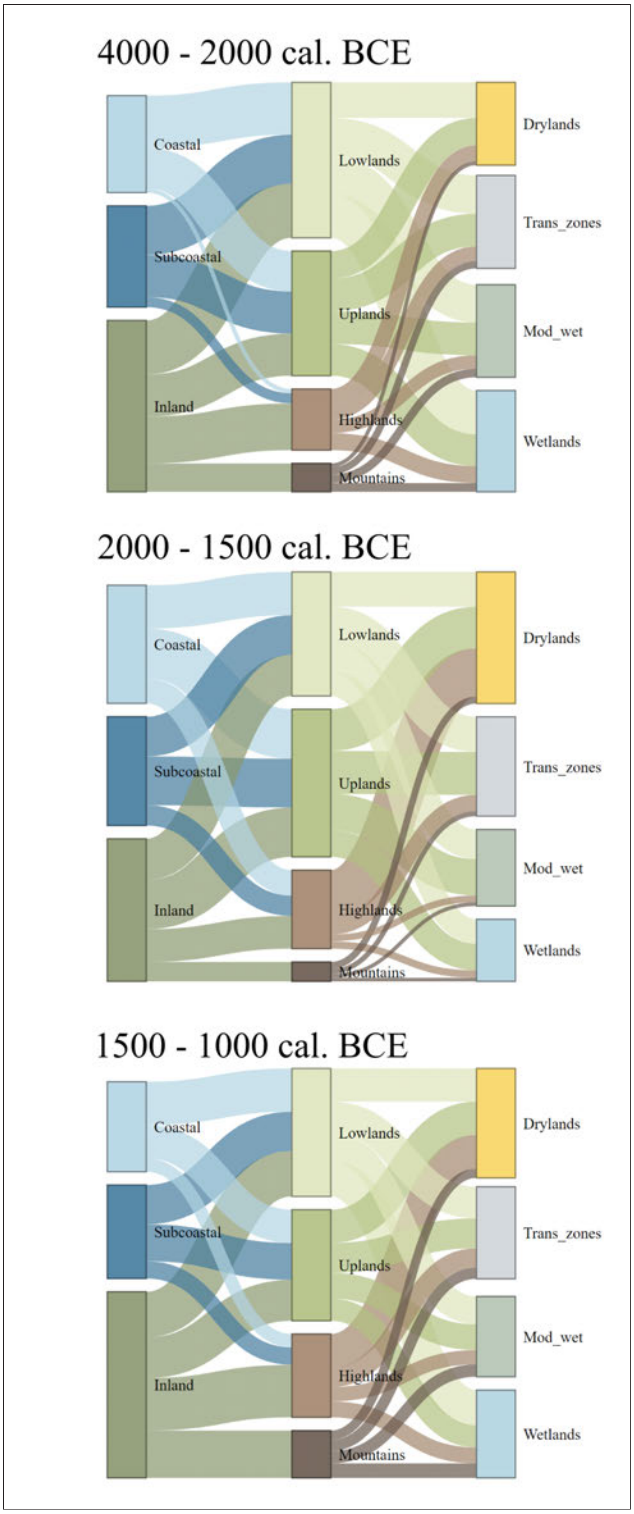

Fig. 16. - Sankey diagrams illustrate the distribution of summed MaxEnt suitability across morpho-hydrological units, for each chronological phase. Flows represent the contribution of different combinations of coastal proximity (Coastal, Subcoastal, Inland), elevation (Lowlands to Mountains), and wetness classes (from Drylands to Wetlands). The width of each band is proportional to the overall suitability associated with that ecological transition. The diagrams reveal how suitable areas shift across the landscape through time, highlighting changes in the relative importance of morphological and hydrological zones.

continue to act as the primary morphological contexts for suitable areas, while highlands and mountains remain marginal, confirming a preference for more accessible and cultivable terrain. On the hydrological side, drylands attract a significant share of flows, especially from lowlands, suggesting a partial shift toward potential drier zones. However, other hydrological categories – particularly transitional and moderately wet areas – still retain a substantial role, pointing to a still-diverse but more structured landscape preference. Overall, the diagram suggests a landscape increasingly oriented toward coastal-lowland systems. Such a trend could align with the archaeological evidence for fortified coastal centres, suggesting that communities deliberately anchored themselves to coastal plains, not only for subsistence but also to participate in emerging maritime networks.

Phase 3 (1500-1000 cal BCE). The flows passing through highlands and mountainous zones are visibly stronger than in previous phases, indicating an increased potential for exploitation in more elevated and rugged terrain. Considering also the maps (fig. 15 left column), this shift may reflect a diversification of settlement or land-use strategies involving less accessible zones. On the hydrological side, the diagram shows a more balanced distribution across all categories: drylands, transitional zones, moderately wet areas, and wetlands are all well represented, suggesting a broader ecological engagement. Compared to earlier phases, the overall structure appears more complex and less selective, pointing to a potentially more complex interaction with the landscape and a wider tolerance for varied environmental conditions.

The second stage of this part of the analysis focuses on the investigation of thermotypes associated with the suitability maps, in order to understand which climatic settings were most likely to host the communities under scrutiny. Thermotypes are climatically defined, reflecting the intensity and duration of seasonal warmth and cold, and they effectively delineate ecological zones critical for vegetation, agriculture, and settlement suitability [20]. Thermotype categories (Tab. 3) allow us to delineate fine-scale climatic belts of the study area, with spatial resolution that captures landscape-scale thermal regimes. Thermotypes were mapped across the Italian peninsula using the WBCS implementation of Pesaresi et alii (2014), which provides a robust national-scale framework [21].

The Sankey diagram (fig. 17) visualises the distribution of modelled suitability across bioclimatic zones (thermotypes) for each chronological phase.

The first phase (4000-2000 cal BCE) shows a markedly selective pattern, with suitability values almost entirely concentrated within the Mesomediterranean zone. This suggests a strong preference for areas with moderate seasonal variability and consistent rainfall – conditions well-suited for mixed agro-pastoral strategies.

[20] López Fernández and López Fernández 2018; Pesaresi *et alii* 2014.

[21] Pesaresi *et alii* 2014, p. 544; Rivas-Martìnez *et alii* 2011.

Thermotype	***Itc (×10 °C)***	***Tp (×10 °C)***	***Environmental Conditions***
Inframediterranean	451-515	2401-2600	Coastal plains, frost-free winters, elevations typically < 200 m
Thermomediterranean	351-450	2101-2400	Coastal/low hills, limited frost, warm summers
Mesomediterranean	221-350	1501-2100	Inland hills and low plateaus, seasonal frost possible, notable thermal variability
Supramediterranean	≤ 220	901-1500	Mid-montane slopes (~600–1200 m), cold winters, brief warm period
Oromediterranean	—	675-900	Lower mountain belt, cold winters with regular snow cover
Thermotemperate	291-350	2001-2175	Interior uplands, moderate cold, moderate elevation
Mesotemperate	191–290	1401-2000	Mid-altitude interior terrain, colder winters, shorter summers
Supratemperate	≤ 190	1101-1400	High subalpine regions, long snow season, short warm interval
Orotemperate	—	381-800	Alpine areas, harsh cold, persistent snow, high elevation
Cryorotemperate	—	1-380	Nival/periglacial fringe, minimal warm season, intense cold
Gelid	—	0	Permanent ice or snowfields, no positive degree accumulation

Table 3. - Thermotypes classification scheme used as a reference for analysing climatic niches associated with transformations in settlement patterns in this study (reworked after Pesaresi et *alii* 2014, Table 7); only some of these thermotypes characterise the macroregion under scrutiny.

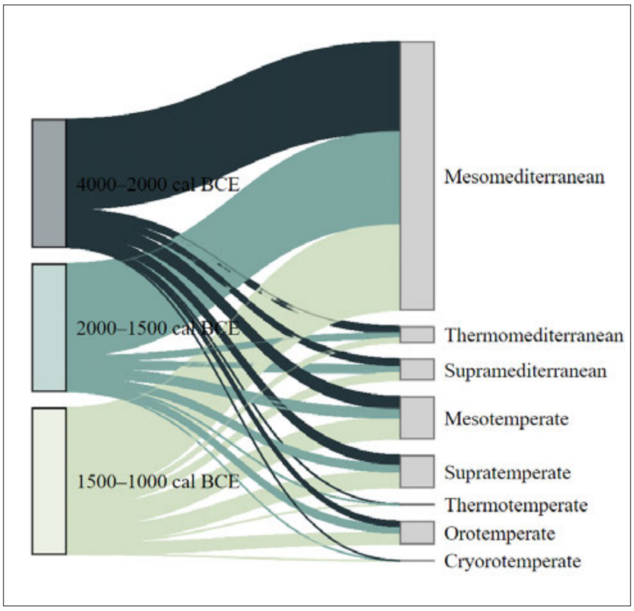

Fig. 17. - Sankey diagrams illustrate the distribution of summed MaxEnt suitability across thermotypes for each chronological phase. Flows indicate the share of overall suitability connected to different thermal zones. The width of each band is proportional to the suitability associated with that transition.

The second phase (2000-1500 cal BCE) reflects a largely comparable pattern, indicating overall continuity. Minor flows begin to appear toward slightly cooler zones such as the Supramediterranean and Mesotemperate belts, hinting at a slow shift or diversification in land-use strategies.

A clearer transformation emerges in the third phase (1500-1000 cal BCE). Here, suitability spreads across a broader range of thermotypes, including temperate and montane zones such as the Supratemperate, Orotemperate and Cryorotemperate. This wider ecological engagement, as already highlighted by the MaxEnt models and by their integration with the morpho-hydrological units, may reflect not only improved adaptability to upland and marginal zones but also a shift in mobility patterns and seasonal exploitation regimes.

Despite this gradual expansion, the Mesomediterranean zone remains central across all phases, underscoring its long-term ecological stability and attractiveness for settlement and subsistence.

This step allowed the integration of continuous landscape suitability maps, generated by MaxEnt based on archaeological evidence within the landscape, with discrete morpho-hydrological categories derived from topographical features and climatic belts, through the implementation of thermotype maps.

It is important to emphasise that the data discussed in this paragraph do not represent actual site distributions, but rather their probabilistic distributions, higher values in one phase do not guarantee occupation, but it does show where that phase offers the best combination of soils, topography and climate. Therefore, the analysis focuses on inductive probabilistic models that move beyond strict presence-absence patterns, yet remain inherently subject to margins of error, as illustrated by standard deviation curves and related maps [22] (fig. 15).

This methodological approach aimed to offer additional insights into human-environment interaction, explicitly addressing uncertainties inherent in territorial data and research biases. It also incorporated various environmental factors potentially influencing the trajectories of cultural landscape transformation. Nonetheless, the resulting interpretations must be critically assessed, considering cultural factors within an appropriate contextual framework, gradually refining the analysis from broad macro-regional dynamics to specific local contexts. For instance, why did areas identified as highly suitable lack empirical evidence of occupation? Do these represent underexplored zones, or were other factors influencing settlement choices? Conversely, were locations deemed less suitable truly underutilised, or did they host other community activities? These questions will be thoroughly examined in the following chapter.

[22] See also MaxEnt outputs in supplementary materials. Link: https://enricolucci.github.io/MODLAND-R-code-for-MaxEnt/

5.
Models in context: community-scale readings of the lived-in landscape

In this chapter, I shift from the broad-scale settlement patterns and ecological inquiries previously presented towards a more contextual analysis that critically evaluates spatial models. The focus is intentionally directed at the community-scale experience, closely examining how communities interacted with specific ecological niches and constructed meaningful places through their daily and seasonal activities. Specifically, it will be considered the Fucino basin and its surrounding areas and the northern and part of central Apulia, including the Gargano promontory, coastal wetlands, the Tavoliere plain, the Subapennine Daunian zone, as well as the northern part of the Murgia plateau.

This objective is pursued by integrating archaeological, economic, and palaeoenvironmental data with insights from the modelling phase. These models will not be set aside; instead, the broader trends identified through modelling will be rigorously tested against detailed local data. This chapter provides ample scope for critical reflection on the processed data and for defining human behaviours within the landscape. Moreover, selected ethnographic case studies will provide interpretative insights for the archaeological record, adding depth to behavioural models and helping to move beyond the deterministic perspective imposed by a straightforward reading of climatic, topographic, and subsistence-related factors.

This approach will allow us to isolate phenomena at the local scale. Although large-scale models are useful for broad analyses, such an extensive and diverse study area – a mosaic of contrasting landscapes – inevitably witnessed distinct trajectories in the construction of cultural landscapes, the exploitation and shaping of environmental niches, and the incorporation of ideological dimensions.

1. People and landscapes across scales

This section examines selected case studies drawn from different ecosystems and chronological phases. The aim is not to cover every period for each area, but to concentrate on those phases most informative for exploring human behaviours within the landscape.

1.1. *Around the lake: landscapes of the Fucino Basin and surrounding territories between the Copper and Bronze Ages*

The first case study examines a northern inland sector of the study area, encompassing the Fucino basin – a former lake enclosed by the Marsicani and Simbruini mountains – as well as nearby intramontane alluvial plains (fig. 1). This area offers a particularly insightful context for exploring the interactions of communities with their surroundings during the Copper and Bronze Ages. Surrounded by steep relief and traversed by a dense hydrographic/river network, the basin encompassed a range of ecological niches-from lacustrine margins to upland slopes, mountainous ridges, and flat alluvial zones (fig. 2).

Based on pollen data [1], arboreal taxa dominate the record, indicating the presence of dense woodland cover characterised by deciduous species such as *Quercus ilex*, *Fagus* and *Carpinus* alongside smaller percentage of conifers such as *Pinus* [2]. This vegetational setting for the period under scrutiny is comparable to other pollen sequences from central Italy [3].

Non-arboreal pollen data – particularly Poaceae and Artemisia – do not indicate significant anthropogenic impact, as also noted by Magri & Follieri (1991, p. 50). Thus, there is no clear evidence of intensive human activity in these environmental niches, at least within the Fucino basin area. These data align with broader palaeoclimatic trends from Zanchetta *et alii* (2012) and Bini *et alii* (2019), which register increased moisture availability and cooler conditions during the mid-Holocene, potentially favouring the expansion of both wetlands and resource-rich woodland ecotones. In such contexts, niche diversification appears to have been a central strategy.

The site distribution map (fig. 1) shows that Copper Age evidence cluster around the southern and eastern lakeshores as well as intramontane plains. These areas correspond to low-elevation, water-accessible zones where alluvial deposits likely enhanced agricultural

[1] Magri and Follieri 1991.

[2] This condition is specifically documented in subzone Z2 of the pollen diagram published by Magri and Follieri 1991, p. 49.

[3] Follieri *et alii* 1989.

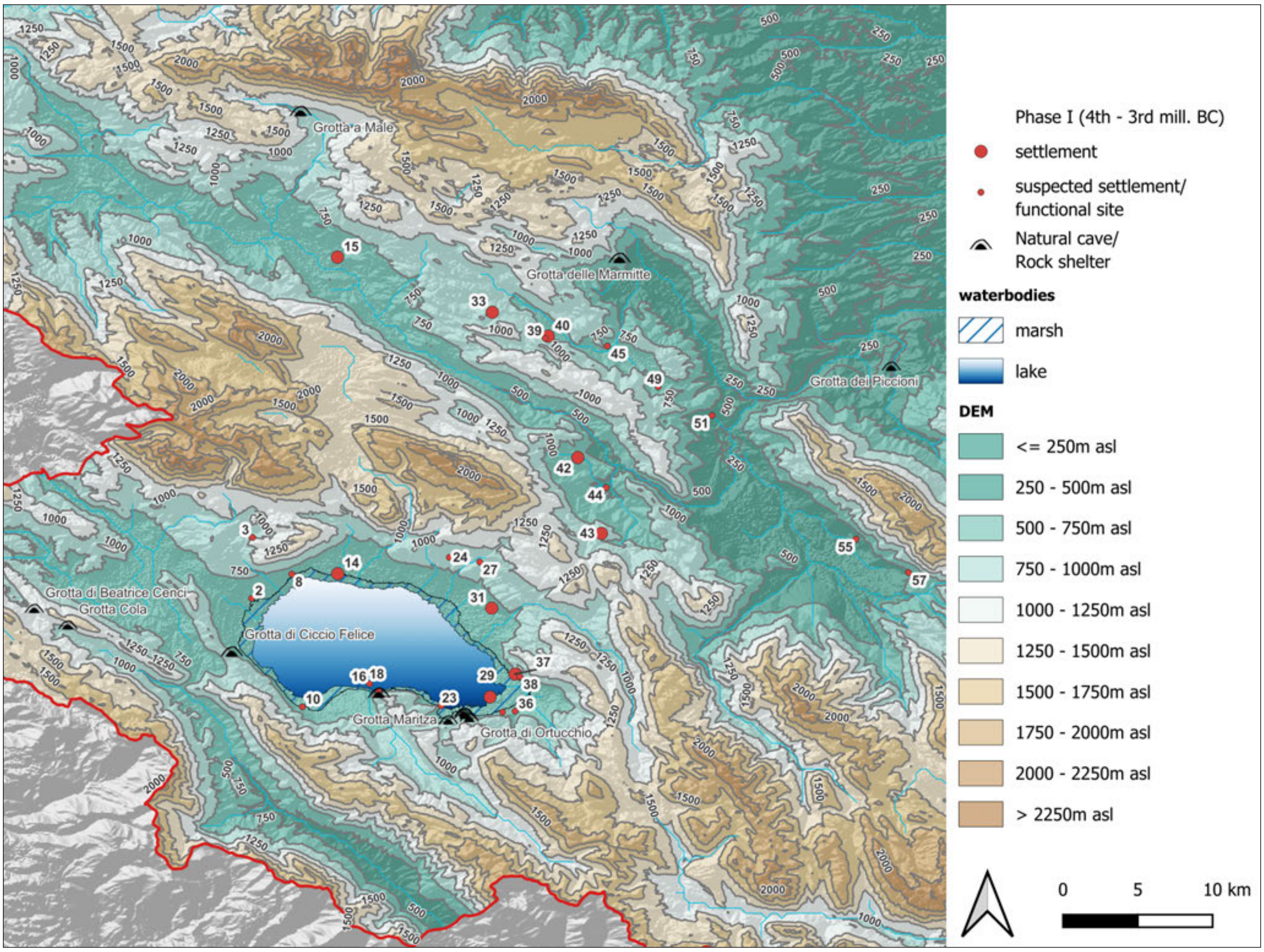

Fig. 1. - Spatial distribution of sites dating to the 4th-3rd mill. BCE analysed in this study. Larger dots indicate sites classified as settlements, while smaller dots represent potential settlements or functional areas. Also shown are natural caves and rock shelters that have yielded Copper Age archaeological evidence.

Fig. 2. - View of the south-eastern portion of the Fucino basin and the surrounding hills. Until the mid-19th century AD, the plain was characterised by the presence of a lake. Following its drainage, it has been used for intensive agriculture, while the hills are still partly covered by dense woodland.

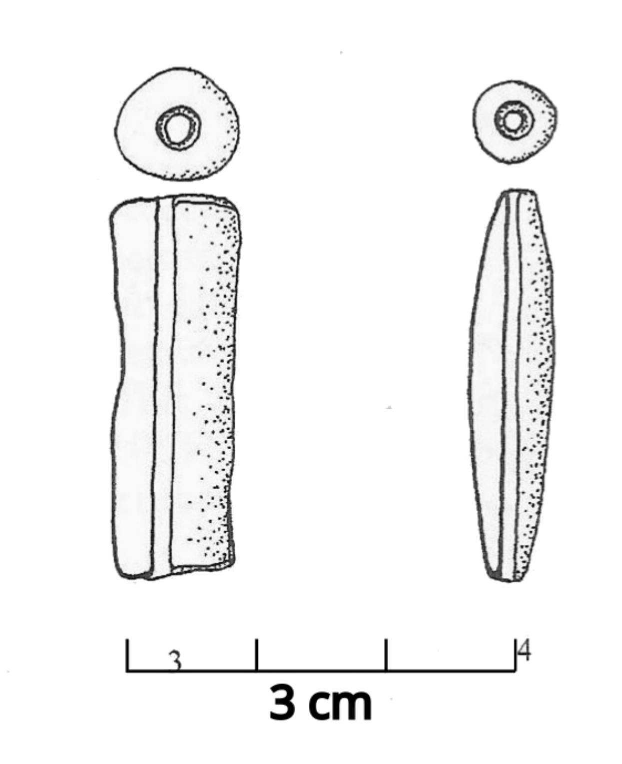

Fig. 3. - Two examples of ceramic objects interpreted as net-weights from the site of Il Mulino (no.16), along the southern lakeshore (after Ialongo 2007, p. 99).

potential. At the same time, their proximity to slopes and uplands – covered by woodland – would have offered access to pasturelands, wild resources, and timber.

The site of Le Coste (no. 37), located on the eastern side of the lakeshores in a slightly elevated position, provides a clear example of diversified subsistence practices in this ecological setting during the Copper Age [4]. Archaeobotanical and faunal remains indicate a mixed economy involving cultivation, herding, hunting, and fishing. The presence of acorns points to the exploitation of woodland resources, while domesticates such as caprines, pigs, and cattle reflect pastoral and farming activities. Wild species including red deer, tortoises, birds, and fish attest to hunting and fishing practices, confirming the broad use of the local environment. The presence of fish remains, in particular, underscores the importance of aquatic resources, as also indicated by ceramic objects interpreted as fishing-net weights from diverse sites around the lake (fig. 3). However, these artefacts cannot be securely dated to a specific phase of Late Prehistory, as their use appears to span a broad chronological range, from at least the Late Neolithic to the Bronze Age.

An important settlement, located along the south-eastern shores of the Fucino lake, was the site of Ortucchio – Strada 28 – (no. 29; fig. 1) [5]. It has yielded a significant quantity of artefacts, chiefly pottery, both through excavation and surface survey, indicating the presence of a settlement. The analysis of ceramic materials suggests two main phases of occupation between the 4th and the 3rd mill. BCE. The earliest phase is documented by sherds attributable to the Conelle culture, characterised by bands of impressed dots [6]. These artefacts, mostly from the trenches excavated by Puglisi in 1956, do not appear to be associated with those of later phases, suggesting an independent and possibly short-lived phase of settlement. This occupation is tentatively dated between the 4th and the early 3rd mill. BCE (Conelle phase D), taking into account radiocarbon dates available for contexts of Marche and Lazio regions [7].

This is followed by a later Eneolithic phase, well represented by ceramics decorated in the style of the Ortucchio culture, in some cases showing Bell Beaker-like influences [8]. This phase, likely dating to the late first half or second half of the 3rd mill. BCE, is supported by a radiocarbon date from the same context (Fi-32: 2885-2340 cal BCE, 1σ [9]) and by comparable evidence from several sites in the southern area of Rome [10]. Data about faunal remains are available from the Copper Age phase of Ortucchio [11] (fig. 4). The broad percentage of red deer remains in the faunal record stresses the meaning of hunting activity for such community, considering that less than 8% of Red deer remains are composed of antlers [12].

At the end of the 3rd mill. BCE, the settlement appears to have been abandoned, with no clear evidence of occupation during the Early Bronze Age. Activity seems to resume during a later phase of the first half

[4] Castiglioni and Rottoli 2003; Radi 2003.

[5] Ialongo 2007, p. 38; Remotti 2001.

[6] Cazzella 2003.

[7] Cazzella *et alii* 2013.

[8] Angeli and Fabbri 2011; Cazzella 2003; Ialongo 2007, p. 38.

[9] This date should be carefully considered, given the extensive timespan it covers – see in Cazzella 2003, p. 225.

[10] For example Casale del Cavaliere (2874–2618 cal BCE, Quadrato di Torre Spaccata (2670–2560 cal BCE), and Osteria del Curato – Via Cinque Frondi (2500-2330 cal BCE), all showing cultural traits consistent with the Ortucchio tradition (Anzidei *et alii* 2007; Boccuccia *et alii* 2000; Carboni and Anzidei 2000).

[11] Wilkens 1991.

[12] *Ibidem*.

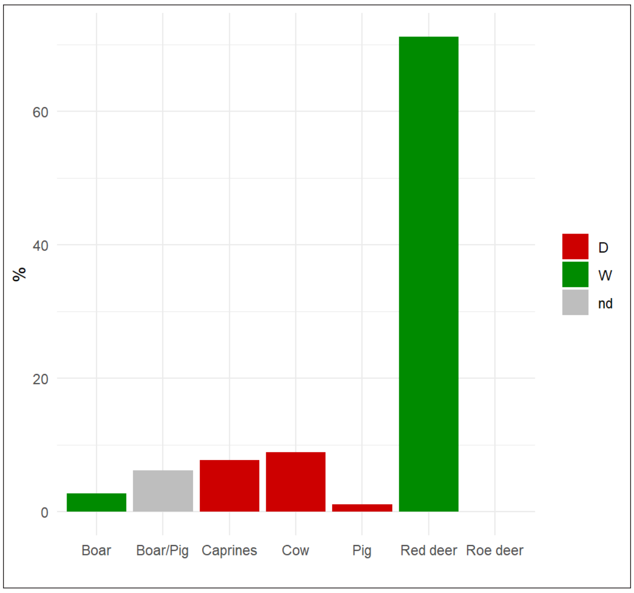

Fig. 4. - Faunal assemblage of the main wild and domestic species from the Copper Age levels at Ortucchio. Red bars indicate domestic species, green bars represent wild species, and grey bars refer to specimens that could not be confidently classified as either wild or domestic (reorganised after Wilkens 1991).

of the 2nd mill. BCE, possibly in connection with a renewed expansion of the lake, as probably witnessed by the presence of pile-dwelling structures [13].

These sites, while among the most informative, are not the only ones attested during the Copper Age along the margins of the lake basin – an area which, due to its environmental characteristics, appears particularly well-suited to the establishment of permanent settlements.

Beyond open-air settlements, several natural caves overlooking the lake basin were more or less intensively frequented during the diverse phases of the Copper Age [14]. Despite the uncertainty due to the lack of published, reliable stratigraphic data, several of these caves appear to have been used as burial places. A particularly interesting case is Grotta Maritza, situated along the southern edge of the lake. This small rock shelter, located on the north-western slope of Monte Praticelle at approximately 50 metres above the plain, was excavated in the 1960s under the direction of A. Radmilli. The investigations revealed a long sequence of occupation, ranging from the Palaeolithic to the historical period. Two burials are attributed to the Copper Age levels: one of an adult without grave goods, and one of a child accompanied by fishing net weights – artefacts that have been associated with the Ortucchio ceramic tradition, although this association remains, in my view, tenuous. Among the ceramic finds, a notable example is a fragment of a sharply carinated bowl decorated with bands of impressed dots, which shows affinities with trans-Adriatic pottery of the Kostolac facies (late 4th mill. BCE), particularly with material from the site of Pivnice [15]. Also present in the Copper Age layers are scale decorations and elbow handles, the latter typically associated with the late 3rd mill. BCE [16].

While acknowledging the challenges of interpreting ideological aspects, the symbolic relevance of these places within the landscape cannot be overlooked – particularly given their lack of clear functional association. This tradition of symbolic use appears to have deep roots, traceable at least to the Neolithic, as demonstrated by the nearby Grotta Continenza [17]. It is noteworthy that such sites, often located in elevated or marginal topographic positions, distinct from settlements and functional areas yet overlooking both them and the lake, seem to retain enduring significance. The burial of a child accompanied by fishing net weights reinforces the idea that these places were meaningfully connected to the perilacustrine communities.

However, the use of caves remains an open and complex question that falls beyond the scope of this work. Nonetheless, it is worth noting that geoarchaeological analyses from Grotta dei Piccioni and Grotta Sant'Angelo – both located in the Abruzzo region and furnished evidence of occupation spanning from the Neolithic to the Bronze Age – have revealed layers of dung indicative of herding activities [18]. Faunal remains linked to these practices are relatively scarce, likely because butchering was carried out elsewhere – an assumption supported by the impracticality of performing such activities directly over manure layers. These findings nonetheless suggest that caves also served practical roles within broader production systems.

Returning to the area under scrutiny, settlement evidence is also present along the northern and eastern edges of the lake perimeter (fig. 1). Higher-altitude

[13] Ialongo 2007, p. 36.

[14] Cazzella 2003, fig. 4; Cosentino *et alii* 2001, 2007.

[15] Cazzella 2003, fig. 3; Maran 1998, tbl. 82; Tasic 1979.

[16] Cosentino *et alii* 2001, p. 160.

[17] Barra Incadorna and Grifoni Cremonesi 1991; Grifoni Cremonesi *et alii* 2011.

[18] Iaconis and Boschian 2007; Wilkens 1996.

areas have likewise yielded multiple traces of occupation that may be significant, although current knowledge is based primarily on survey data. An interesting example is the site of Cerchio – Capazzano (no. 24), known from surface surveys. The site has provided a substantial quantity of material, mostly attributable to the Eneolithic, with only a few sherds suggesting earlier Neolithic activity and no evidence of Bronze Age occupation. Ceramics decorated with scale motifs, often associated with elbow handles featuring button or raised tongue-like tips could be dated to an advanced moment of the Copper Age, probably the second half of 3rd mill. BCE. Some fragments display incised herringbone patterns, possibly indicating influences from the Laterza facies. The assemblage includes biconical spindle whorls, a cylindrical weight, and common domestic forms such as plain-profile bowls, a ladle, and a possible spoon handle. The nature and distribution of the finds suggest that a resident community occupied the area, likely exploiting the undulating intermontane surfaces for both pasture and cultivation, possibly through the terracing of slopes.

The ceramic assemblage from Cerchio – Capazzano shows notable similarities with contexts further to the northeast in the Subequana Valley, particularly at Valle Cerenzana (no. 42) and Le Castagne (no. 43) [19]. In contrast, the similarity with assemblages from contexts closer to the lake basin is less pronounced, despite some widely shared elements such as scale-decorated surfaces and elbow handles. The features that seem more specific to the aforementioned sites are those recalling aspects of the Laterza tradition, such as button-like projections on handles and herringbone incised decorations. A restricted number of ceramic sherds showing influence of Laterza style have been recorded at the sites further east on the Navelli plain, such as S. Callisto (no. 43) [20].

With due caution, this evidence may suggest spheres of connectivity linking diverse peoples and places, with some communities gravitating more strongly toward the uplands – inhabiting the valleys and intramontane plains and likely exploiting them through a mixed agro-pastoral system. In particular, pastoral activities appear to have played a key role, allowing for the use of physiographically complex areas, alongside the exploitation of wild resources. Other communities, located closer to the lake, likely integrated fishing into their subsistence strategies, alongside farming, herding, and hunting as stressed by data from Ortucchio (fig. 4).

During the 2nd mill. BCE, settlement patterns show no major transformations, as communities continued to occupy locations that exploited the same favourable topographic conditions (fig. 5) [21].

The impact of the 4.2 ka event should, however, be considered within the broader climatic transition that followed the eruption of Agnano Monte Spina [22] (AMST, c. 4.5-4.3 ka cal BP), whose effects extended into the early centuries of the 2nd mill. BCE (around 3.8 ka) [23]. This period coincides with the renewed advance of the Calderone glacier, marking the onset of the so-called "Apennine Neoglacial". Cooler and probably wetter conditions developed at higher altitudes, allowing glacial deposits to reform. Inland and upland areas experienced cooler and wetter conditions, which likely contributed to a rise in lake levels, as reported by several studies [24].

The response of the communities living around the lake was not to relocate their settlements but rather to adapt to the changing conditions. Several Bronze Age sites around the lake – such as Celano-Paludi, Ortucchio-Laghetto, and Trasacco – have provided evidence of wooden structures that likely formed an integral part of these settlements [25]. These constructions were likely designed either to cope with seasonal fluctuations in lake levels or to allow for the stable establishment of at least part of the settlement directly on the lake surface.

The number of sites increases during the second half of the 2nd mill. BCE [26] (fig. 6). Lake shores as well

[19] Cosentino *et alii* 2007.

[20] Di Fraia 1996.

[21] The transition between the late 3rd and early 2nd millennium BCE remains poorly understood in this area. The Ortucchio culture (dragged-comb decoration) appears not to extend beyond the 3rd millennium BCE, as confirmed by radiocarbon dates from Latium and some Abruzzese sites (Carboni 2020b). Conversely, the onset of Protoapennine traits is difficult to define, although dates from south-eastern Italy place it at the beginning of the 2nd millennium BCE. Sites with long occupational sequences, such as Ortucchio-Strada 28, Le Coste, and Celano-Paludi, show Protoapennine or Apennine layers directly overlying Eneolithic deposits.

[22] Tephrostratigraphic studies and evidence from glacial phases in the central Apennines, including the Gran Sasso area of Abruzzo, point to a marked climatic deterioration after the AMST eruption (Zanchetta *et alii* 2012).

[23] Bini *et alii* 2019; Zanchetta *et alii* 2012.

[24] Giraudi 1989, 2007.

[25] D'Ercole 1991; Ialongo 2007; Radi 1991; Silvestri 2016.

[26] It should also be taken into account that the relationships between the sequence of ceramic stylistic traditions in this area have not yet been fully understood; it is plausible that Eneolithic features may have persisted for a longer time, and it cannot be

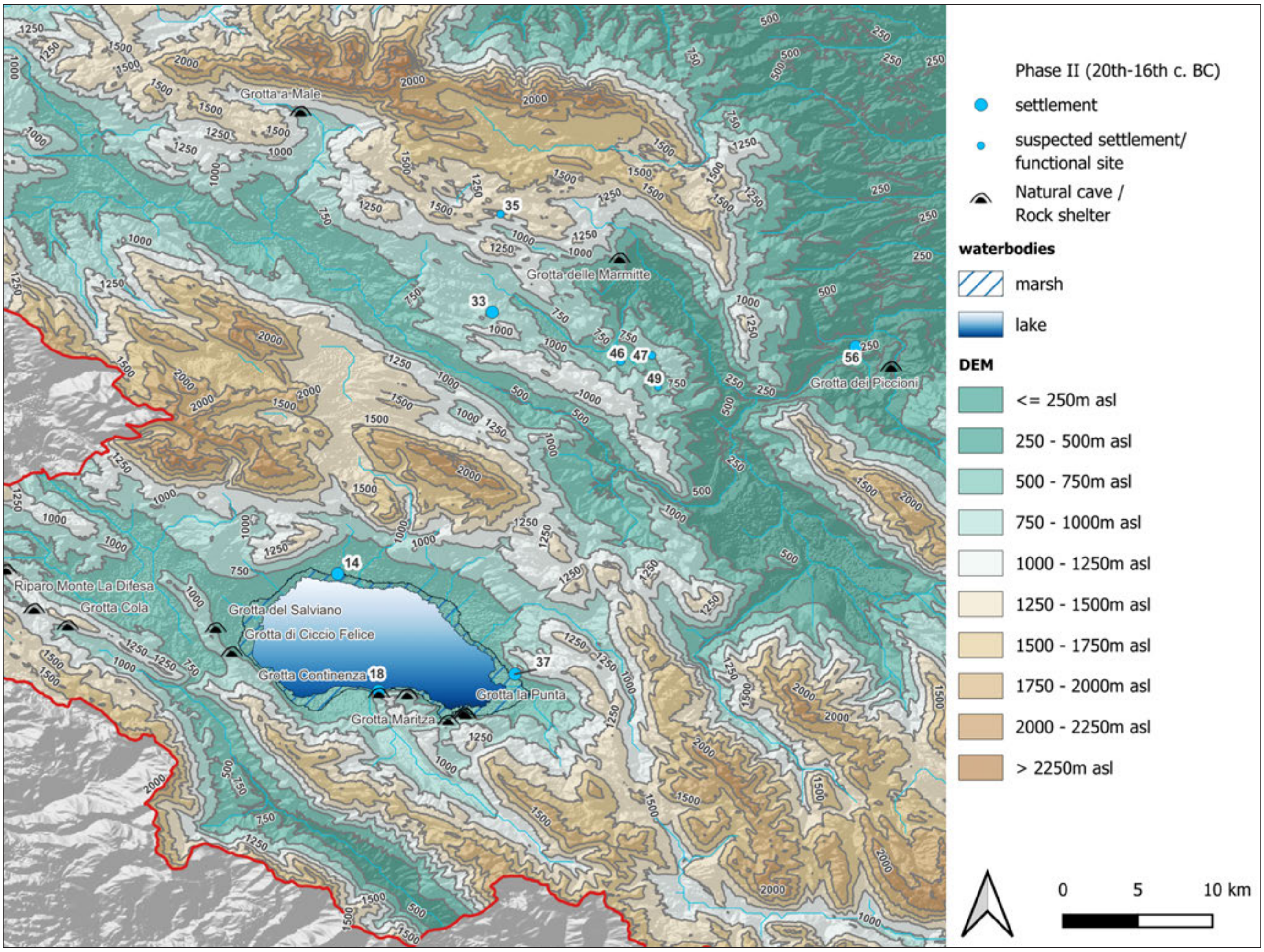

Fig. 5. - Spatial distribution of sites dating to Phase 2 within the Fucino basin and surrounding areas. Larger dots indicate confirmed settlements, smaller dots represent potential settlements or functional areas. Also shown are natural caves and rock shelters that have yielded Bronze Age archaeological evidence.

as intramontane plains and valleys persisted as key environmental places for human settling.

However, it is worth noting that, beyond the lake area, sites located in intramontane valleys rarely occupy the valley floor directly. Instead, throughout all three phases, they tend to exploit marginal zones positioned between the slopes of the surrounding reliefs and the valley bottoms, deliberately avoiding the wettest soils. It may reflect opportunistic choices aimed at combining access to arable valley-bottom resources with dry, stable ground suitable for structures, while ensuring control over both lowland resources and communication routes, as well as enabling the exploitation of higher-altitude pastures during the driest months. Some degree of seasonal vertical mobility or small-scale transhumance cannot be excluded [27], although current evidence remains limited. Dung deposits from Grotta Sant'Angelo, located in the northern part of the Abruzzo region (not in the map), may inform about dynamic pastoral practices, possibly linked to seasonal herding or small-scale vertical mobility within the surrounding uplands [28].

For the area under scrutiny, evidence of agricultural practices is available only for few context, yet they allow to trace a diversified crop spectrum. Cereals dominate, with widespread cultivation of *Triticum dicoccum, T. monococcum, T. spelta, T. aestivum*, and

excluded that the Apennine aspect may have begun earlier than the 15th century BCE.

[27] The isotopic study by De Angelis *et alii* (2021), focused on Neolithic and Eneolithic case studies from Central Italy, reports for the Copper Age site of Celano Pratovecchio (Abruzzo) values consistent with local water resources and no significant outliers, suggesting stable and largely sedentary communities (De Angelis *et alii* 2021).

[28] Iaconis and Boschian 2007.

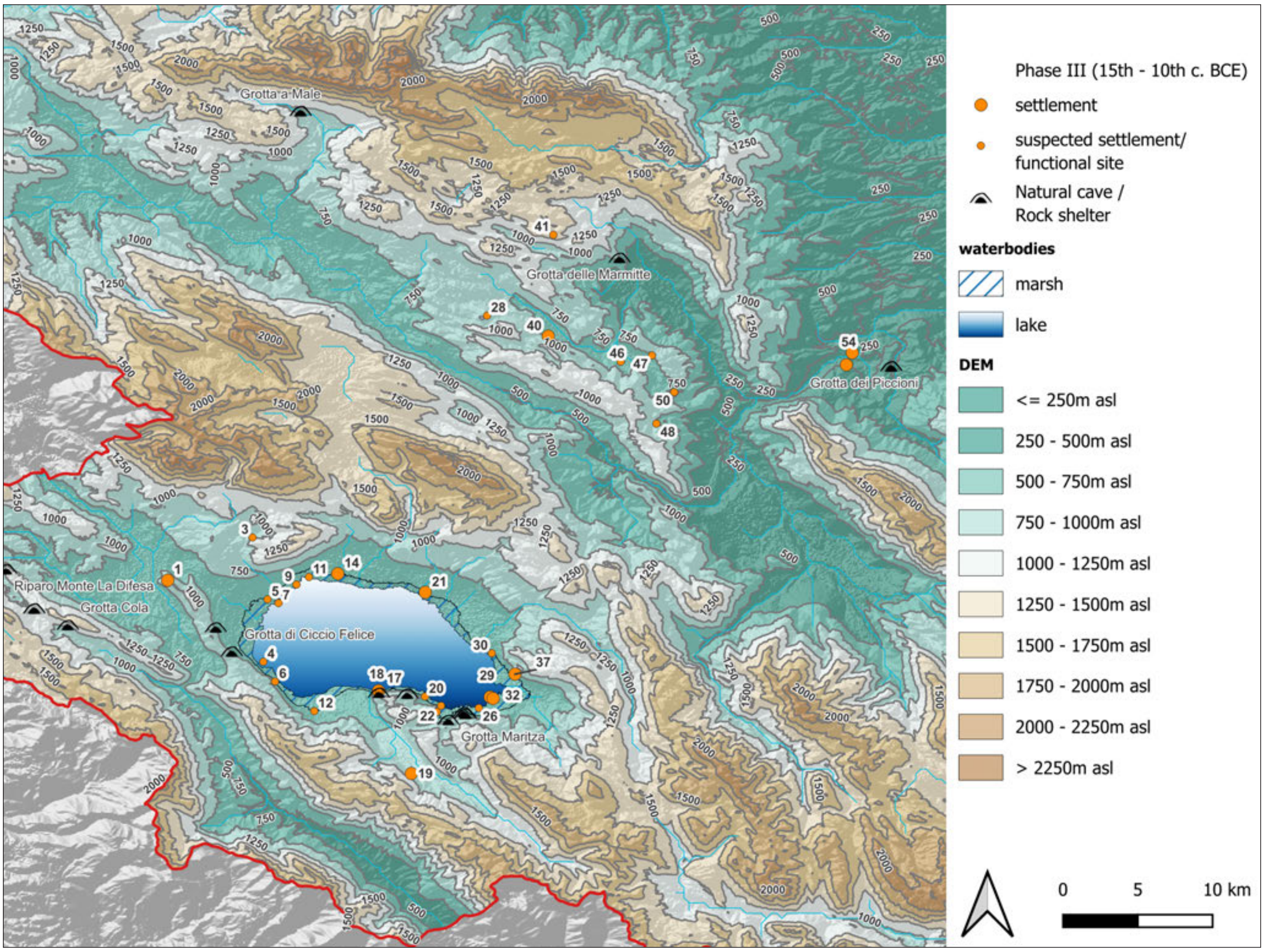

Fig. 6. - Spatial distribution of sites dating to Phase 3 across the study area. Larger dots indicate settlements, smaller dots represent potential settlements or functional areas Also shown are natural caves and rock shelters that have yielded Copper Age archaeological evidence.

Hordeum. At Celano Paludi (no. 14), the assemblage is particularly rich, including not only these cereals but also *Panicum miliaceum* and *Vicia faba* [29]. Le Coste (no. 37) shows a similar reliance on hulled wheats (*T. dicoccum, T. monococcum, T. spelta*) and barley, while Madonna degli Angeli attests to *T. aestivum, T. dicoccum*, and Hordeum [30]. The predominance of traditional hulled wheats suggests continuity with Eneolithic agricultural practices, while the presence of free-threshing wheat *(T. aestivum)*, millet, and *Vicia faba* reflects a possible diversification over time, although the limited quantity/quality of data makes such an interpretation highly tentative.

A comprehensive analysis of faunal data from Bronze Age sites in the Abruzzo region is provided by the work of J. De Grossi Mazzorin and C. Minniti, and the data discussed in the following section are drawn from their study [31]. Faunal assemblages indicate a mixed livestock economy, with a consistent predominance of domestic species (caprines, cattle, pigs), while wild animals played only a marginal role. An informative case study is Cerchio La Ripa (no. 21). In levels dating to the 14th cen. BCE, domestic species account for around 94% of the faunal remains, with a slight predominance of caprines over cattle, while pigs are comparatively less frequent (fig. 7) [32]. Age-at-death profiles suggest that cattle were slaughtered mostly after the fourth year of life, implying their use

[29] Coubray 1991.

[30] Angeli *et alii* 2011; Castiglioni and Rottoli 2003; Mieli *et alii* 2003.

[31] De Grossi Mazzorin and Minniti 2003.

[32] In this work, the estimates are calculated on the total number of remains, whereas in the authors' study they are based on the total domestic fauna; for this reason, the figures differ from those in the original publication (De Grossi Mazzorin and Minniti 2003).

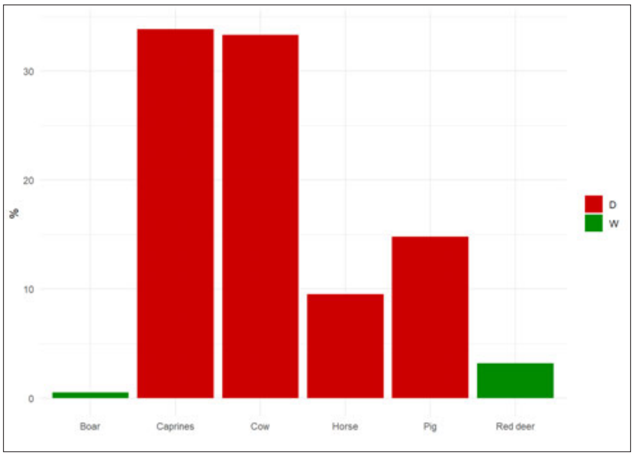

Fig. 7. - Faunal assemblage of the main wild and domestic species from the Middle Bronze Age levels at Cerchio la Ripa. Red bars indicate domestic species and green bars represent wild species (reorganised after De Grossi Mazzorin and Minniti 2003).

as draught animals and for secondary products before slaughter. Caprines, with an average withers height of about 57 cm, were mainly raised for meat and wool, with most animals slaughtered as adults (between the second and third year), while only a small proportion lived beyond four years. Pigs were generally slaughtered between 18 and 36 months; their slower growth, compared to modern breeds, may reflect a diet based largely on acorns and forest resources, consistent with free-ranging husbandry.

Of particular interest is the significant presence of horse, which is unusually high in the Fucino basin compared to other Italian regions: at Cerchio La Ripa (no. 21), equine remains represent ca. 9.5% of the faunal assemblage, and horses are also attested at Celano Paludi (no. 14), Trasacco (no. 18), and Madonna degli Angeli (no. 53), especially in Final Bronze Age levels of this latter. A suggested by the authors [33], this pattern has been interpreted as linked to the availability of open spaces suitable for horse breeding [34].

The varied landscape of these inland areas, from intramontane plains to rugged mountain reliefs, likely made pastoral activities a central element of community subsistence. Their dynamic and highly adaptable nature allowed them to exploit different types of terrain – even steep slopes – and to respond effectively to seasonal changes (fig. 8). On that subject, the positioning of settlements in marginal zones between valley floors and slopes would have facilitated access to both lowland areas and upland pastures. Cave contexts provide additional insights, particularly into possible seasonal mobility. At Grotta a Male and Grotta Beatrice Cenci, caprines are the dominant domestic species, with a high proportion of juveniles, a pattern also seen at Grotta dei Piccioni. These assemblages could be interpreted as evidence of seasonal herding practices, likely short-range transhumance, aimed at exploiting upland pastures during favourable periods. However, the Late Bronze Age levels of Grotta a Male and Grotta Sant'Angelo show a different pattern: the three main domestic species occur in more balanced proportions, with a slight predominance of cattle at Grotta Sant'Angelo and caprines still slightly prevailing at Grotta a Male, suggesting a possible shift towards more mixed herding strategies in these later phases [35]. Yet, isotopic evidence for such mobility is still lacking.

The exploitation of wild resources during the Bronze Age in Abruzzo appears to have played a secondary, yet not negligible role, complementing the agropastoral economy and expanding the sphere of interactions with surrounding landscape by communities.

At Celano Paludi, wild fauna includes red deer (*Cervus elaphus*), roe deer (*Capreolus capreolus*), wolf (*Canis lupus*), fox (*Vulpes vulpes*), and various birds (*Aves*), suggesting occasional hunting of both large and small game [36]. Such activities were likely aimed not only at supplementing the diet with meat, but also at obtaining by-products, such as fur and skins. Cerchio – La Ripa presents a similar spectrum, with red deer, wild boar (*Sus scrofa ferus*), fox, and birds; zooarchaeological analyses indicate that wild species constitute about 5% of the faunal assemblage [37], confirming their marginal dietary contribution. Grotta Sant'Angelo has yielded remains of red deer, roe deer, hare (*Lepus sp.*), and wild boar, attesting to opportunistic hunting, likely integrated into broader pastoral activities.

At Madonna degli Angeli, the wild component includes red deer, roe deer, brown bear (*Ursus arctos*), fox, and tortoise (*Testudo hermanni*), while Trasacco stands out for the presence of lynx (*Lynx lynx*),

[33] De Grossi Mazzorin and Minniti 2003.

[34] The sub-zone Z2 of the Fucino pollen sequence shows a decrease in woodland cover; however, it is difficult to correlate this evidence with the cultural phases under analysis (Magri and Follieri 1991).

[35] De Grossi Mazzorin and Minniti 2003; Iaconis and Boschian 2007.

[36] De Grossi Mazzorin 1991, 1998.

[37] De Grossi Mazzorin and Minniti 2003.

Fig. 8. - Goats and a donkey graze along the rugged slopes of the Magnola Mountains in the Abruzzo Apennines (photo by E. Lucci).

alongside badger (*Meles meles*), wild rabbit (*Oryctolagus cuniculus*), and birds, suggesting occasional exploitation of diverse faunal resources, probably linked to the use of their fur [38].

Although botanical wild resources are less well documented, indirect evidence suggests their importance. At Celano Paludi, wild plant remains broaden the picture of resource use, with taxa such as hazelnut (*Corylus avellana*), cornelian cherry (*Cornus mas*), acorn (*Quercus* sp.), blackberry (*Rubus* sp.), and elderberry (*Sambucus nigra*), indicating the gathering of fruits and nuts that likely integrated the diet and supplemented animal fodder [39]. According to De Grossi Mazzorin and Minniti (2003), at Cerchio – La Ripa the slower growth rates of pigs, inferred from age-at-death profiles, suggest a diet largely based on forest products, particularly acorns, likely collected in nearby woodland areas [40]. In this regard, it is worth reflecting on the role of woodland, which should not be viewed merely as a non-anthropized space – something external to the community used only for wood gathering or occasional wild resource collection – but rather as an area fully integrated into productive economic practices. At Celano – Paludi (14) the identification of several wood taxa from the site, including oak (*Quercus sp.*), willow (*Salix sp.*), poplar (*Populus sp.*), hop-hornbeam (*Ostrya carpinifolia*), beech (*Fagus*), maple (*Acer sp.*), ash (*Fraxinus*), juniper (*Juniperus*), and yew (*Taxus sp.*), provide important environmental

[38] *Ibidem*.

[39] However, as suggested by the author (Coubray 1991), these remains may also reflect an expansion of surrounding vegetation into the settlement area during a transitional phase of site abandonment.

[40] Ervynck and Lentacker 2007; Hadjikoumis 2012.

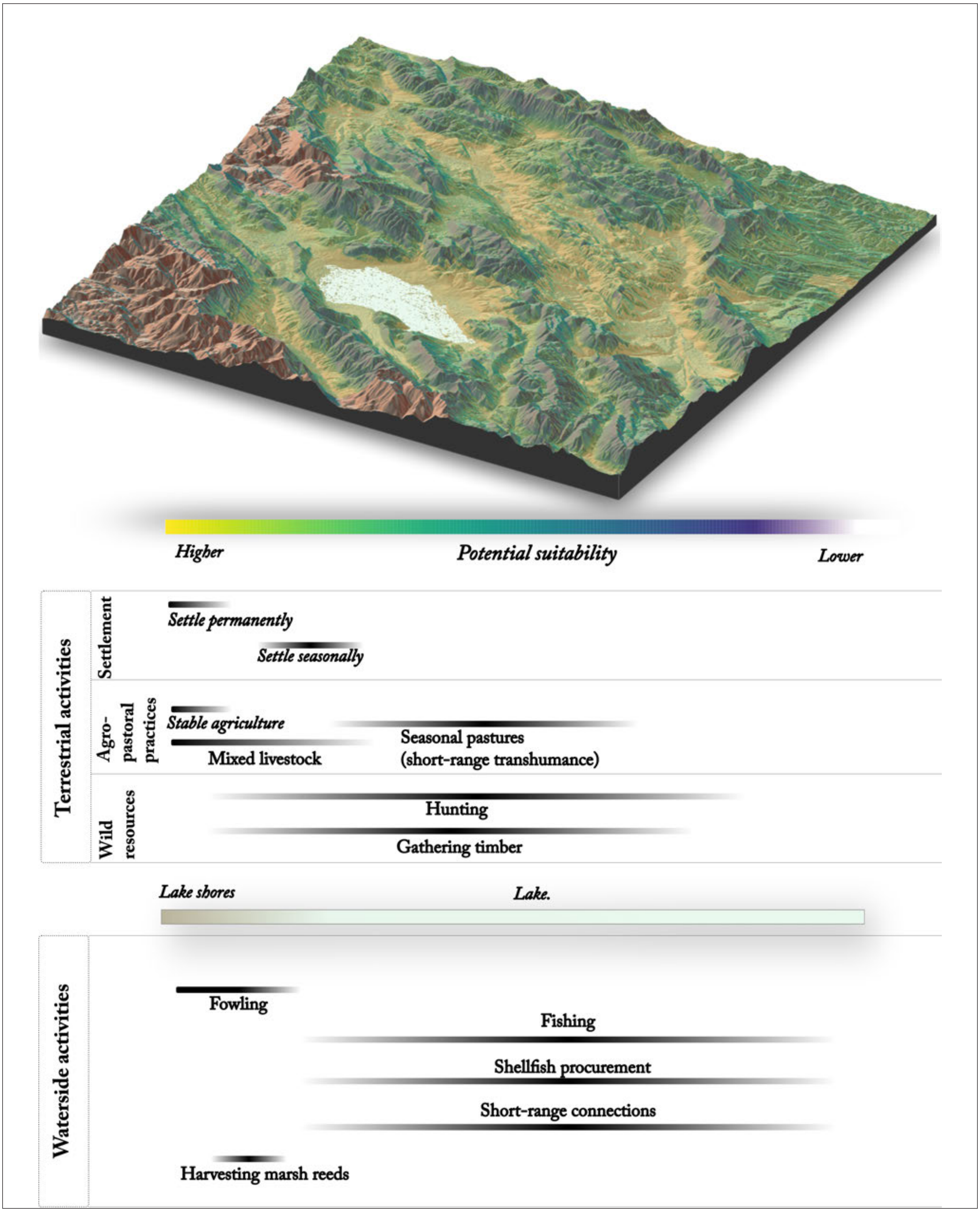

Fig. 9. - 3D visualisation of a cumulative MaxEnt suitability model for settlement distribution, integrating outputs from all three chronological phases. Green to yellow areas indicate higher modelled suitability values, potentially corresponding to zones of more intensive or potential persistent human use. Blue/Fully transparent areas reflect very low or null suitability. The composite surface offers a synthetic view of long-term ecological attractiveness, highlighting areas where favourable conditions may have persisted over time. The bar below links different ranges of suitability to corresponding economic activities. Lines connect each activity to its estimated ecological threshold, offering an interpretive key to possible patterns of land use.

context and evidence of woodlot exploitation. These taxa indicate a mosaic of woodland formations surrounding the settlement, which were likely exploited not only for construction and fuel but also as grazing areas for herds and as a source of fodder and forest products for semi-free-ranging pigs.

In summary, the data depict communities interacting with specific ecological niches within a highly varied landscape, shaped by complex physiography, hydrology, and vegetation. Although the overall human impact on the surrounding environment does not appear to have been significant, the establishment of more stable Bronze Age settlements – including pile-dwelling structures – required regular maintenance and a continuous supply of timber. From a Niche Construction Theory perspective, even these limited practices, such as selective grazing, woodland exploitation, and localised clearances, may have contributed to modifying the immediate environment, thereby creating conditions that were inherited by subsequent generations and that influenced later settlement choices [41].

This dynamic is visually captured in fig. 9, which shows MaxEnt-derived suitability surfaces for the three phases under scrutiny. Despite diachronic environmental fluctuations, the maps reveal a notable persistence of highly suitable areas, particularly in ecotonal zones between intramontane plains, valley floors and uplands. This spatial consistency suggests that communities continued to favour well-established ecological niches rather than initiating large-scale landscape transformations.

The possible decline in woodland cover toward the end of the 2nd mill. BCE [42] may instead reflect macro-regional climatic trends [43] rather than direct anthropogenic pressure. Nonetheless, these interpretations must remain cautious, given the limited resolution of palaeoenvironmental and archaeological datasets currently available.

1.2. *Communities of the late prehistory in the mosaic landscapes of northern Apulia*

The Daunian hills and foothills, the low undulating plains of the Tavoliere, the rugged reliefs of the Gargano promontory, and the coastal wetlands with their marshes and waterbodies form the mosaic landscapes of northern Apulia (fig. 9). The area under scrutiny also partially includes the northern part of the Murgia plateau, generally considered part of Central Apulia.

One of the most significant transformations in this territory is the reshaping of the coastal zone, particularly along the stretch south of the Gargano promontory. During the Late Prehistory, the coast west of the present-day Gulf of Manfredonia was characterised by a broad, continuous lagoon. Over the course of millennia, geomorphological changes – especially those affecting the inner shoreline, surrounding marshes, and the dune system separating the lagoon from the open sea – gradually altered its configuration. At its greatest extent, the lagoon stretched from approximately the mouth of the Ofanto River in the south to the area south-west of modern-day Manfredonia in the north (fig. 10; see also fig. 3, chapter 2) [44]. Coastal wetland environments played a central role in the transformation dynamics of the cultural landscape in this region, serving as resource-rich ecosystems particularly favourable to stable communities, yet fragile niches highly exposed to climatic fluctuations in the central Mediterranean.

Evidence from pollen sequences, sediment cores, isotopic studies and archaeological contexts reveals a landscape in ongoing ecological transformation, shaped by both natural processes and increasing anthropogenic impact.

During the Early and first part of the Mid-Holocene, the Central Mediterranean experienced generally warm and humid climatic conditions, which are reflected in the region's geomorphological features and vegetation cover [45]. The vegetation was primarily composed of mesophilous taxa – plant species adapted to environments with moderate and regular moisture – indicating the presence of well-structured woodland ecosystems and consistent water availability [46]. Mixed woodland covered the higher elevations, though woodlots extended down to the plains and coastal areas [47]. Such environmental conditions provided a favourable ecological backdrop for the spread of Neolithic communities, as well as the emergence of long-lasting settlements – *ditched villages* –across the Tavoliere plain during the early 6th mill. BCE [48]. In this regard, coastal wetlands played a key role for Neolithic groups, as ecological niches offering highly

[41] Laland *et alii* 2016; Odling-Smee and Laland 2011.

[42] Magri and Follieri 1991.

[43] Kaniewski and Van Campo 2017; Molloy 2023.

[44] For further information see also §2.1.

[45] Combourieu-Nebout *et alii* 2013; Fiorentino *et alii* 2013; Sadori *et alii* 2011.

[46] Fiorentino *et alii* 2013, fig. 7.

[47] Caldara *et alii* 2002.

[48] Fiorentino *et alii* 2013.

diversified natural resources and good soil conditions [49].

From the second half of the 6th mill. BCE onwards, archives suggest an oscillating shift towards increasingly arid conditions. This is particularly evident during the 5th mill. BCE. The deterioration of climatic conditions likely reduced the suitability of the Tavoliere landscape for stable agricultural exploitation, contributing to the abandonment of ditched villages and the emergence of less structured and possibly seasonal forms of land use [50].

The decrease in Late Neolithic and Copper Age settlement evidence on the Tavoliere and coastal lowlands has generally been interpreted as evidence of a shift toward inland or upland occupation, particularly in the Subappennine hills. However, this model has been increasingly challenged. For example, the site of Fontanarosa Uliveto [51], not far from the Tavoliere plain, provides evidence for continued use of the area during the Late Neolithic. A stone-cist funerary structure associated with the Diana facies was inserted into a Neolithic ditch that had already been infilled. Moreover, the upper layers of the ditch fill contained materials associated with both the Diana and Piano Conte facies [52]. These findings suggest that, rather than a complete abandonment, the area experienced a shift in how it was perceived and utilised by later communities.

Turning again to palaeoenvironmental contexts, from the Late Neolithic period (late 5th mill. cal BCE) onwards, there is a marked increase in the availability of vegetation and climate data for the area under investigation [53]. In fact, the trend of climatic deterioration did not continue linearly, as palaeoenvironmental data from both northern and southern Apulia point to a window of environmental recovery during the 4th mill. BCE, marked by a modest increase in arboreal pollen percentages [54]. Between 5950-4200 cal BP (ca. 4000-2200 BCE – Copper Age) data from Lago Battaglia, located to the east of the Gargano promontory, reflect an environment dominated by a typical Mediterranean evergreen assemblage – including *Quercus ilex, Olea, phillyrea, and Pistacia* – indicating mild, dry conditions along the coastal zone. In contrast, the uplands supported a stable mixed oak woodland composed of deciduous and mesophilous taxa such as *Ostrya, Carpinus orientalis*, and *Corylus*. Higher still, beech (*Fagus*) and yew (*Taxus*) were probably present, occupying the most humid and elevated ecological niches on the promontory [55].

Studies on the ancient transformation of the Salso/Salpi lagoon have highlighted that between c. 6300 and 4000 cal BP, the Tavoliere plain and adjacent coastal wetlands were characterised by an extensive woodland coverage. Arboreal pollen values indicate a mixed woodland composed of both evergreen (*Quercus ilex*, *Olea*, *Pistacia*, *Phillyrea*) and mesophilous deciduous species (*Quercus robur*, *Fagus*, *Carpinus*, *Ostrya*, *Alnus*). These assemblages reflect stable, humid climatic conditions supporting woodland ecosystems. In contrast, the Salpi Lagoon record – derived from a more dynamic and marginal coastal setting – shows an earlier decline in arboreal cover between 5250 and 4260 cal BP [56]. This shift, marked by the rise of xeric and riparian taxa such as Juniperus and Alnus, likely reflects localised environmental stress related to lagoonal closure and salinisation, rather than broad climatic deterioration.

The distribution map (fig. 10) shows the case studies [57] examined within the study area that can be attributed to the Copper Age (4th and 3rd millennia BCE). Overall, it is clear that inland areas played a central role in terms of occupation; nevertheless, evidence is also present along the coastal zones, both to the north and south of the Gargano promontory.

One of the most important inland contexts is the settlement of Valle Cancelli (no. 99) [58]. Identified during preventive excavations, it was located on a wide interfluvial terrace with good environmental potential, the site revealed semi-subterranean structures, hearths, pits, and domestic features suggesting a stable or repeatedly used settlement. The pottery assemblage aligns with the Macchia a Mare stylistic aspects. Two radiocarbon dates (3951-3780 BCE and 3711-3644 BCE) place the main settlement phase

[49] Cassano and Manfredini 1987a; Recchia *et alii* 2024a.

[50] Combourieu-Nebout *et alii* 2013; Fiorentino *et alii* 2013; Peyron *et alii* 2017.

[51] Not on the map.

[52] Cassano and Manfredini 1987b.

[53] Boenzi *et alii* 2006; Caldara and Simone 2012; Caroli and Caldara 2007; Susini *et alii* 2023.

[54] Caldara *et alii* 2002; Caroli and Caldara 2007; Di Rita and Magri 2009; Fiorentino *et alii* 2013, p. 1313.

[55] Caroli and Caldara 2007, p. 324.

[56] Susini *et alii* 2023.

[57] It is important to note that this study does not include funerary contexts, but focuses solely on settlement evidence – such as the distribution of surface materials potentially related to occupation phenomena, or functional areas that may be associated with localised settlement activities.

[58] Tunzi *et alii* 2012a.

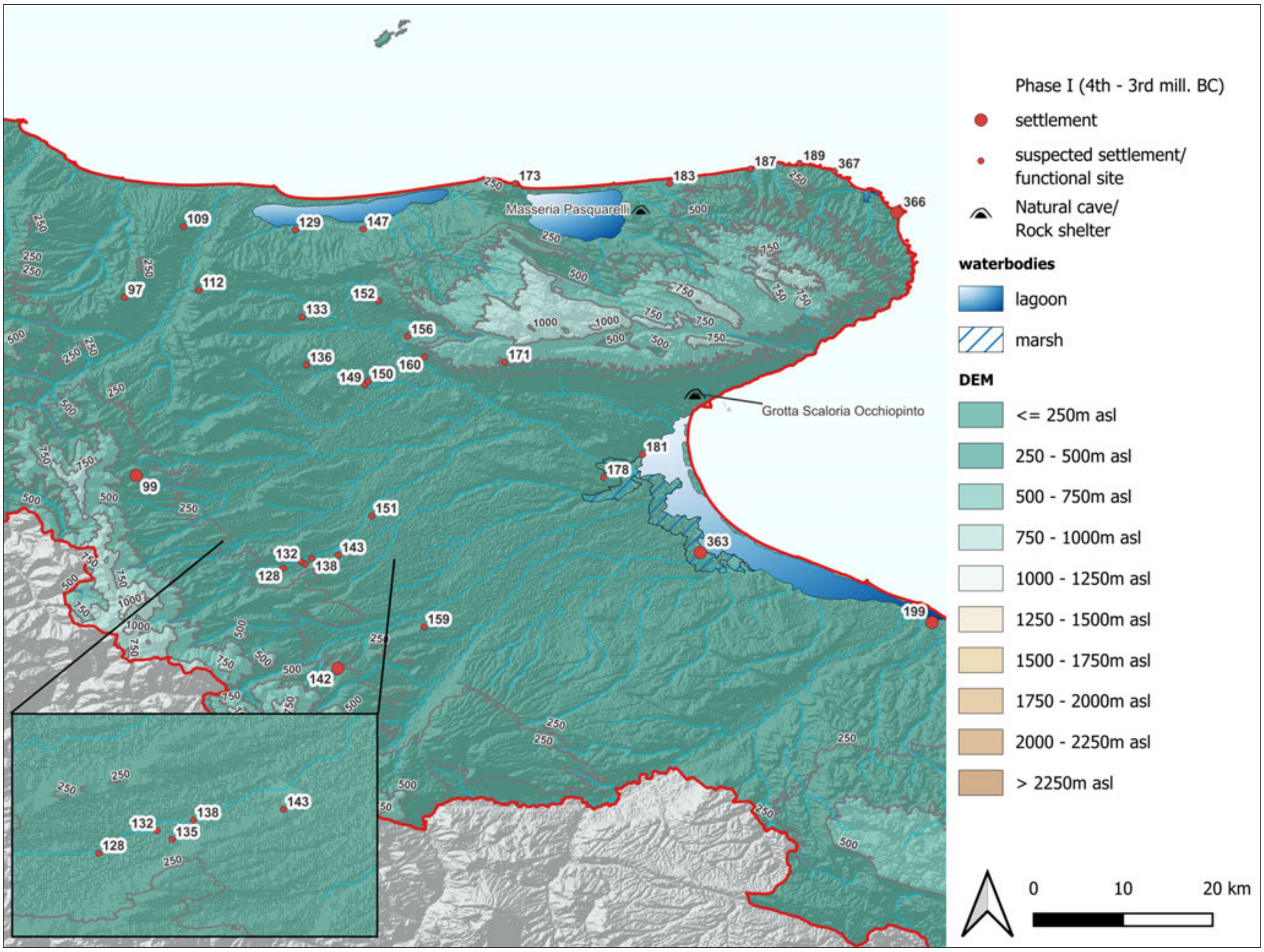

Fig. 10. - Spatial distribution of sites dating to Phase 1 (4000-2000 cal. BCE) in the northern Apulia. Larger dots indicate confirmed settlements, smaller dots represent potential settlements or functional areas. Also shown are natural caves and rock shelters that have yielded Copper Age archaeological evidence.

– characterised by the presence of large huts – in the first half of the 4th mill. BCE. The site's position between the Tavoliere plain and the uplands suggests a strategic location for the seasonal exploitation of diverse ecological niches and for supporting a range of economic activities. On that subject, the faunal assemblage from Valle Cancelli offers valuable insights into the economy. It is dominated by domestic species – particularly sheep/goat (47.3%) and cattle (27.4%) while pigs seem to be less represented (7.5%) (fig. 11). The high proportion of caprines suggests a largely pastoral economy with a focus on meat production[59]. The cattle remains, while fewer in number, account for over half the total weight, pointing to their significant role in meat provisioning. Hunting played a marginal role, likely opportunistic, and mainly

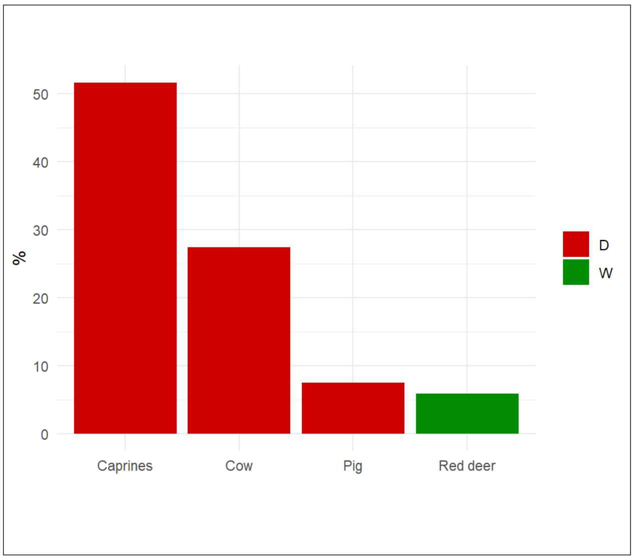

Fig. 11. - Faunal assemblage of the main wild and domestic species from the Copper Age levels at Valle Cancelli. Red bars indicate domestic species and green bars represent wild species (reorganised after Tunzi *et alii* 2012a).

[59] *Ibidem*, p. 29.

involved deer. The limited presence of pig – an animal typically associated with the exploitation of woodland resources, as also noted in the discussion of central Apennine contexts – and of wild fauna may suggest that the area around the settlement was relatively open and not densely wooded. Overall, the faunal evidence supports the interpretation of a sedentary agropastoral community inhabiting a mixed landscape composed of open fields and marginal woodland zones. This aspect should not necessarily be interpreted as being at odds with the environmental evidence and should be considered with caution, as it may reflect a cultural choice and/or the outcome of landscape modification processes carried out by the community in the immediate surroundings of the settlement, such as woodland clearance within a limited radius of everyday activities. Unfortunately, with the exception of Valle Cancelli, case studies providing insights into the economy of Copper Age communities are lacking for this territory, making it difficult to explore these aspects in greater depth.

Although no extensive archaeobotanical or faunal data are available, Tegole di Bovino is another crucial context [60]. Geoarchaeological studies suggest long-term environmental and climatic dynamics, and human responses, from the 4th mill. BCE to the threshold of the 2nd mill. BCE. In fact, sedimentary sequences within the site's ditches, wells, and pits display episodes of rapid erosion and colluviation, interspersed with layers of stable soil development. This alternation reflects climatic fluctuations between dry and humid phases, likely impacting land use and settlement continuity [61].

The distribution map (fig. 10) suggests a tendency during the Copper Age toward the exploitation of liminal zones – such as interfaces between plains and uplands or between lowlands, wetlands, and the sea. This pattern likely reflects a strategic attempt to secure integrated access to diverse ecological niches. While interpretations based on a single site remain tentative, the central role of caprine husbandry at Valle Cancelli aligns well with a model of land use that included access to different grazing areas, providing seasonal pastures for flocks. Additionally, some communities may have deliberately positioned themselves within the landscape to maximise resource availability and mobility. Although archaeological evidence is still limited, even the coastal sites may mark the early structuring of routes and landing points – developments that would become more pronounced in the later Copper Age (second half of the 3rd mill. BCE) and fully established during the Bronze Age (2nd mill. BCE).

The absence of settlement data from the central Tavoliere should be treated with caution. However, it is plausible that the area's environmental homogeneity and its susceptibility to arid episodes between the Late Neolithic and the Copper Age may have made it less attractive for occupation during this period.

At the end of the 3rd mill. BCE, palaeoenvironmental records show a decline in arboreal pollen and the spread of halophytic and herbaceous taxa [62]. These plants – adapted to saline conditions or typical of open, non-forested landscapes – suggest increasing salinity and reduced woodland cover. This change could align with the broader 4.2 ka climatic event affecting the Mediterranean Basin in diverse ways [63].

This further climatic shift – characterised by increasingly arid conditions – combined with the anthropogenic impact that human communities likely began to exert from the 2nd mill. BCE onwards, contributed to a profound and lasting transformation of the northern Apulian landscape, particularly across the Tavoliere plain and its coastal zones [64]. The outcome was the establishment of a more open landscape with limited tree cover.

In this process of woodland retreat, human impact cannot be ignored, but it is crucial to be cautious in assessing its magnitude. The archaeological record clearly shows an increase in settlement evidence – whether in the form of actual or potential settlements – during the Bronze Age (fig. 12 and fig. 13). How far it is possible to interpret this pattern as a proxy for demographic increase remains an open question, especially in view of the limited archaeological visibility of Copper Age occupations discussed

[60] Tunzi *et alii* 2013.

[61] Mariani *et alii* 2020.

[62] Caroli and Caldara 2007; Di Rita *et alii* 2011.

[63] Bini *et alii* 2019; Di Rita and Magri 2019; McKay *et alii* 2024.

[64] The scale of this impact remains to be fully defined and may not have been particularly intense, as the decline in arboreal cover appears to precede the emergence of long-lived settlements often regarded as the main agents of environmental pressure. For example, in the Gargano sector, the Lago Battaglia (Caroli and Caldara 2007) pollen record shows that clear signals of sustained anthropogenic activity – such as increased fire frequency and the spread of cultivated and synanthropic taxa – only become evident from around 2700 cal BP (Iron Age), underlining that earlier vegetation changes were primarily driven by climatic and geomorphological processes rather than by human agency.

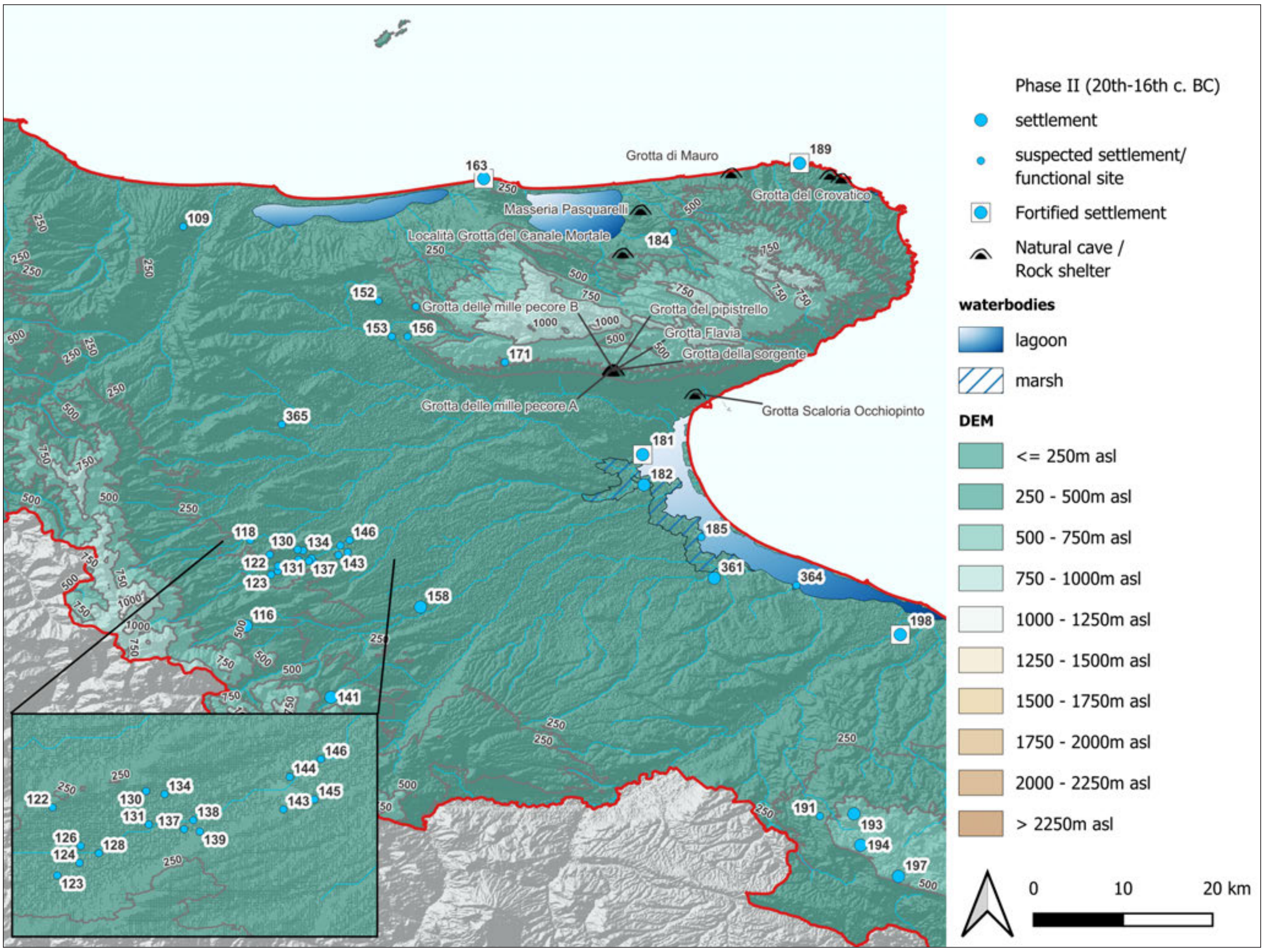

Fig. 12. - Spatial distribution of sites dating to Phase 2 (2000-1500 cal. BCE) in the northern Apulia. Larger dots indicate confirmed settlements, smaller dots represent potential settlements or functional areas. Also shown are natural caves and rock shelters that have yielded Bronze Age archaeological evidence.

above. A plausible explanation is an increase in settlement stability, which may have amplified the human footprint in the surrounding landscape. Nonetheless, population density does not appear to have been particularly high. For example, the high density observed in areas like the Celone Valley (see inset in fig. 13) likely reflects short-range relocation and reconstruction by the same community, rather than the presence of multiple contemporaneous settlements [65].

It is also important to account for research biases: fieldwork limitations have certainly shaped our current understanding, and the number of occupied sites was likely higher than presently documented. That said, this underestimation applies to both the Bronze and Copper Ages.

In this context, there is little evidence to support the idea of a significant demographic increase during the 2nd mill. BCE that would have greatly intensified land use. Even in the case of Coppa Nevigata – arguably one of the largest and most enduring sites in the region – estimates indicate that the land required for agriculture was relatively modest, even when accounting for fallow practices [66].

The distribution maps of sites dating from the Copper Age (4th and 3rd mill. BCE) through the two halves of the 2nd mill. BCE reveal a certain degree of continuity in settlement choices, often oriented toward specific ecosystems – particularly coastal wetlands and elevated inland areas. At the same time, major river corridors such as the Fortore also appear to play a central role, serving as natural routes connecting the

[65] This has been hypothesised, for example, for the Brindisi Murgian area (Recchia and Ruggini 2009).

[66] Cazzella *et alii* 2021; Recchia *et alii* 2024a.

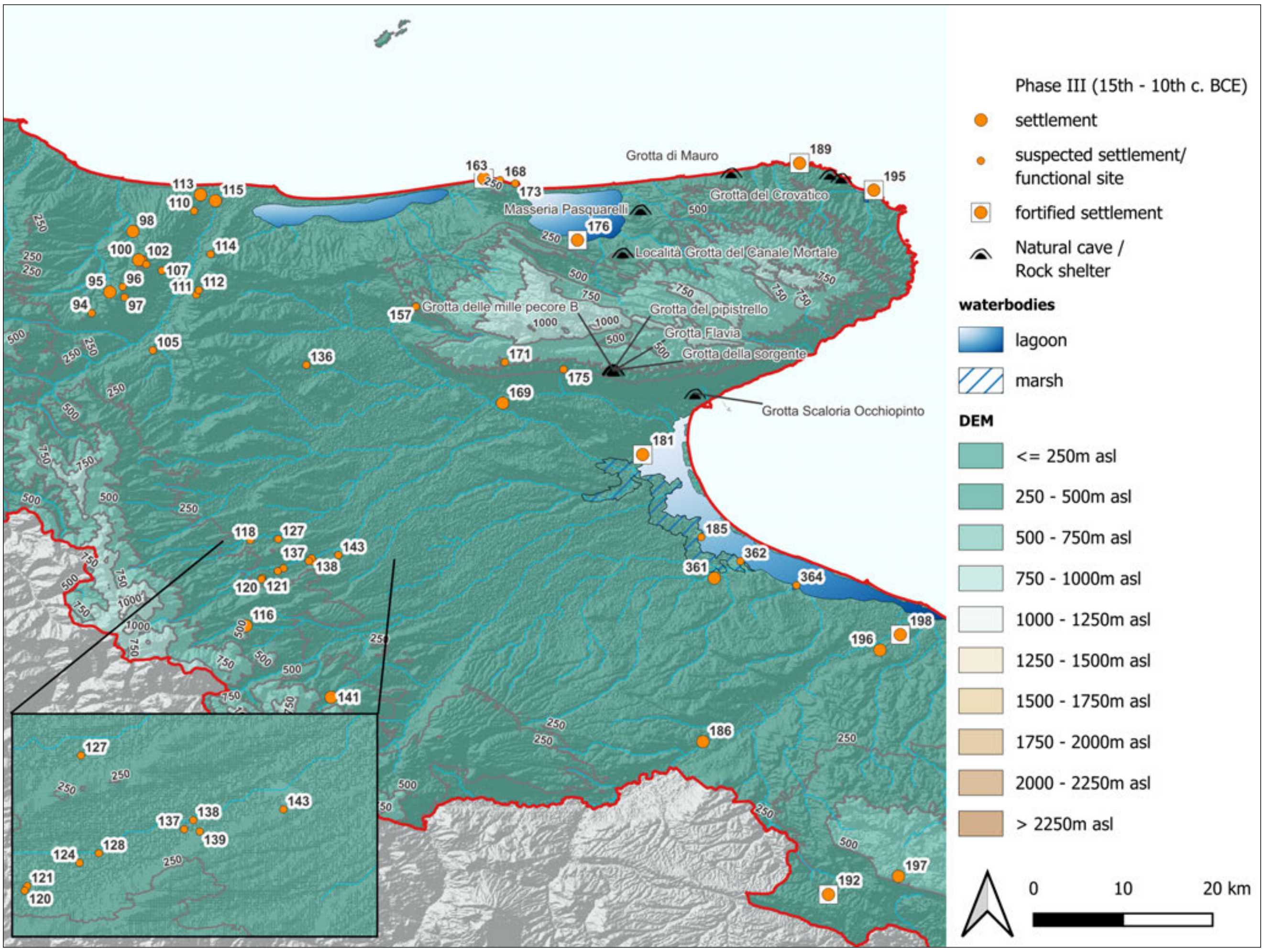

Fig. 13. - Spatial distribution of sites dating to Phase 3 (1500-1000 cal. BCE) in the northern Apulia. Larger dots indicate confirmed settlements, smaller dots represent potential settlements or functional areas. Also shown are natural caves and rock shelters that have yielded Bronze Age archaeological evidence.

coast with the interior (fig. 13). Similar dynamics likely applied to rivers further north, such as the Biferno (not included in the current map) [67].

Even within a framework of topographic continuity, it is essential to reflect on the transformation in the *meaning* of places over time. As previously mentioned, during the Copper Age, certain dynamics – such as a growing interest in strategic locations for movement or territorial control – may have begun to take shape. However, it is in the Bronze Age that this role becomes more clearly defined. A key development is the emergence of fortified settlements along the coast or in areas connected to the sea, which can be linked to the increase in both short- and long-distance maritime exchange across the central Mediterranean.

Yet, their significance extends beyond connectivity. Within these communities, specialised craft activities also took place – for instance, one of the most striking aspects is the early exploitation of *murex* shell for the extraction of purple dye at the settlement of Coppa Nevigata, a high-value product that may be associated with elite consumption and long-distance networks [68]. In parallel, the production of olive oil – already attested in earlier phases – points to the emergence of specialised practices, likely influenced by Eastern Mediterranean traditions [69], as well as to new forms of landscape exploitation [70].

[67] Barker 1995.

[68] Recchia *et alii* 2024a, b; Recchia and Minniti 2018.

[69] Evans and Recchia 2003; Recchia *et alii* 2024a.

[70] Which would intensify in the final phases of the 2nd millennium BCE (Di Rita and Magri 2009; Primavera and Fiorentino 2021).

In this context, coastal wetlands were not only providers of diverse subsistence resources, but also played an active role in socio-political transformation, contributing to the development of specialised production and the weaving of inter-community long-range networks. Moreover, the expansion of maritime exchange could have stimulated specialised shipbuilding and maintenance activities, which in turn required a steady supply of timber – whether through direct procurement or exchange with inland communities.

The increase in archaeological data is accompanied by a growing body of economic evidence from well-studied contexts in northern Apulia and, more broadly, across the southeastern Italian peninsula (chapter 3, Tab. 3)[71].

Economic data from Bronze Age contexts of this area stress a flexible subsistence system based on the integrated exploitation of cultivated and wild resources. Archaeobotanical data from sites like Coppa Nevigata, Madonna del Petto, and Carluva document the presence of various cereals (*Hordeum vulgare, Triticum dicoccum, T. monococcum, and T. aestivum*) and pulses (including *Lens* and *Vicia*)[72]. Thus, alongside cereal production – possibly linked to extensive field systems – horticulture represented an important resource for communities, likely involving the exploitation of land surfaces located closer to settlements.

But how might these activities have been organised within the landscape?

Clearly, this is a question that must be addressed in hypothetical and interpretive terms, based on the available data, with the aim of reconstructing a plausible scenario of the landscape as lived and perceived by the communities under study. It is likely that cereal cultivation and horticulture were carried out by exploiting land surfaces close to the settlements, although – as proposed in some reconstructions[73] – these may have been located within a radius of 1-2 km from the settlement itself. This extent is not only related to the actual surface required for annual agricultural production, but also to the possible implementation of crop rotation and fallow strategies. Moreover, while some evidence suggests the use of large agricultural fields already during the Bronze Age[74], the diversity of taxa recorded in archaeobotanical data, as well as in pollen sequences, seems to support – at least in the view of the present author – a more mosaic-like configuration of the land around settlements. That is, an environment not entirely defined by productive fields but interspersed with areas of spontaneous vegetation. Such a landscape configuration would not reflect a limited capacity of Bronze Age communities to impact their immediate surroundings, but rather an intentional process of constructing a co-productive ecological niche – one in which cultivated resources were interwoven with the availability of wild plant resources near the settlements[75]. To these, we might also add grazing activities, such as pig husbandry within woodland areas, or caprine grazing on fallow surfaces. On that subject, anthracological remains such as *Ficus*, *Vitis*, and *Prunus* derive reflect the collection and use of wood for fuel or other domestic activities[76]. Their presence indicates that these species were available in the surrounding landscape and exploited as part of local resources. While not direct evidence of fruit consumption, their identification may indirectly suggest the potential availability – and possibly even the use – of such resources at a dietary level.

As previously mentioned, the exploitation of olive trees remains a debated topic. In northern Apulia – despite early signs of use during the initial phases of the Bronze Age at Coppa Nevigata – there is no clear evidence of an actual olive cultivation, even in later periods. While olive remains are present in the anthracological record, they may derive from non-domesticated forms of the plant, suggesting gathering rather than systematic arboriculture. However, more broadly, archaeobotanical evidence from other sites across the Apulia region – along with pollen data from Alimini Piccolo, as highlighted by Primavera *et alii* (2017) – shows a gradual increase in Olea pollen starting around 1800 BCE, with a peak reached by approximately 1100 BCE[77]. Notably, in the late centuries of the 2nd mill. BCE, *Olea* appears more frequently in pollen records but less in charcoal remains. This contrast could reflect a change in how olive trees were used – possibly pointing to more selective harvesting of wild or semi-domesticated trees for fruit, as also suggested by the high number of olive stones found in archaeological layers.

[71] De Grossi Mazzorin *et alii* 2017; Minniti 2021; Primavera *et alii* 2017.

[72] Primavera *et alii* 2017; Recchia *et alii* 2021.

[73] Cazzella *et alii* 2021; Recchia *et alii* 2024a.

[74] Saccoccio 2020.

[75] Berglund *et alii* 2014; Eriksson *et alii* 2021.

[76] Primavera *et alii* 2017.

[77] Di Rita and Magri 2009. This trend, linked to a rise in evergreen species, suggests a shift toward more Mediterranean-like climate conditions.

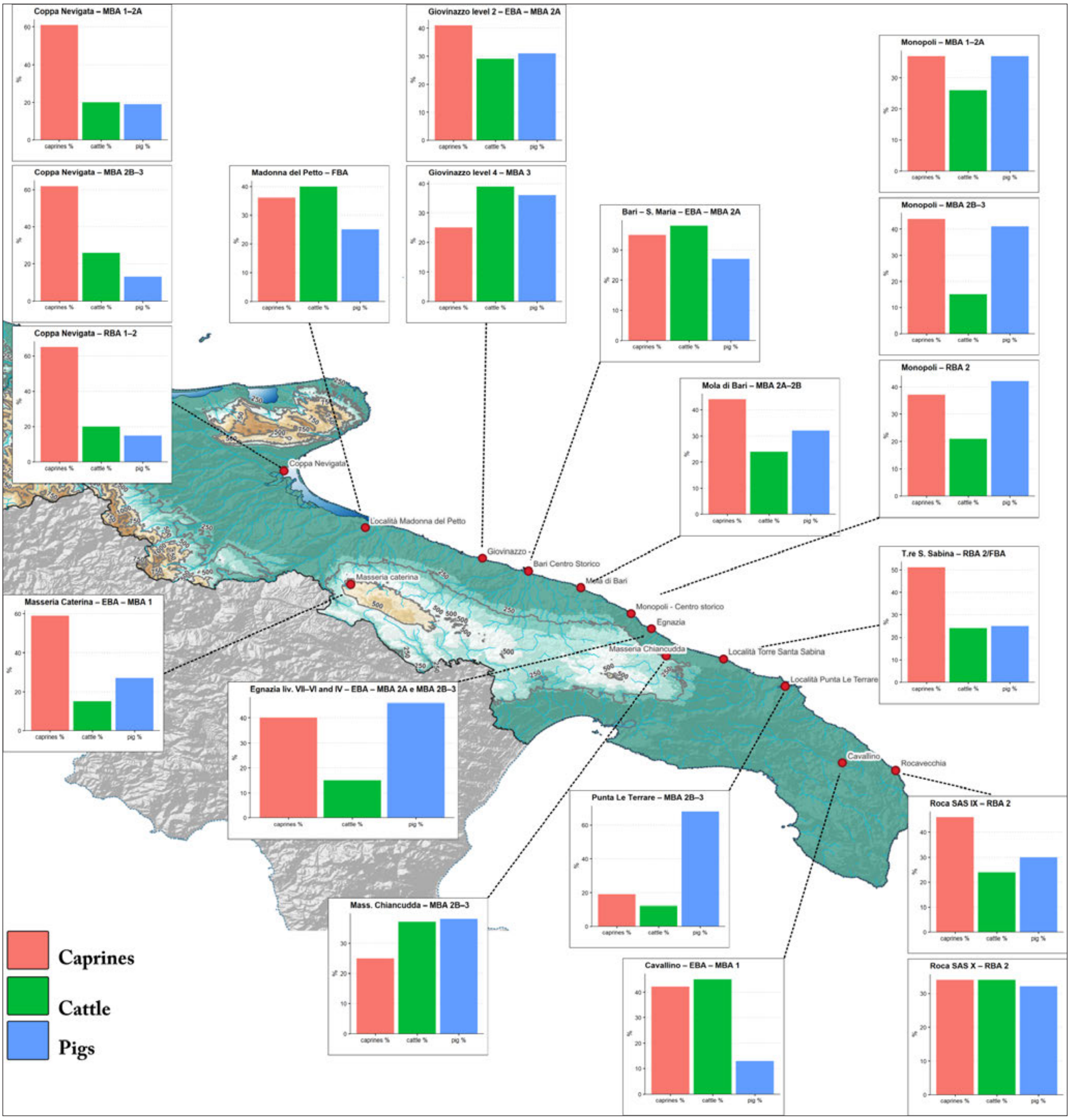

Fig. 14. - Distribution of the percentage of the main domestic species from various Bronze Age sites in the Apulia region (adapted from Minniti 2021). Chronological phases follow the framework outlined in Cazzella (2010).

Turning to animal resources, faunal assemblages reveal a dominance of caprines [78], with cattle and pigs playing more variable roles depending on the site (fig. 14). Notably, Coppa Nevigata and Masseria Caterina consistently show a dominance of caprines, indicating pastoral strategies characterised by low pig use and moderate reliance on cattle [79]. The marked prevalence of caprines may reflect both their adaptability and their suitability for physiographically complex ter-

[78] De Grossi Mazzorin *et alii* 2017; Minniti 2021; Siracusano 2012.

[79] It should nonetheless be taken into account that cattle provided a higher meat yield than caprines, even though their size during the Bronze Age was significantly smaller than the modern average.

Fig. 15. - A mixed flock of sheep and goats grazing in the Garagnone Valley, Alta Murgia National Park (photo by E. Lucci).

rains (fig. 15), such as those of the Murge area. At the same time, the importance of secondary products should be considered; in particular, evidence for purple dye production at Coppa Nevigata may point to a strategic role for caprines (i.e. wool working) in specialised craft activities [80].

However, among secondary products, cheese-making practices deserve consideration, even though it is difficult to reconstruct a complete picture. Nonetheless, in terms of understanding human dynamics within the landscape, this type of production may have influenced the function and significance of certain places. Particularly relevant is the need for salt in the cheese-making process – a resource likely obtained from the coast. This has been hypothesised, for example, for the site of Vasche Napoletane (no. 364), but similar activities may well have taken place at other coastal or lagoon-edge locations [81], still characterised by this kind of activities (e.g. Margherita di Savoia). It is also important to recognise the wider role of salt: not only in livestock management, leather tanning, and food preservation, but also – to avoid primitivist readings – as a means of enhancing flavour in food consumption. In this context, circulation between coastal and inland areas was probably significantly active, and given its close connection with pastoral practices, the role of pastoralism in shaping local and meso-regional networks remains an open and compelling line of enquiry [82].

[80] Frei *et alii* 2017; Sabatini *et alii* 2018, 2019.

[81] On this topic, see studies conducted along the Tyrrhenian coast (Alessandri *et alii* 2019; Bulian *et alii* 2024).

[82] Migliavacca 2024.

The exploitation of wild faunal resources opens up further avenues for interpretation – not only regarding the variety of animals utilised but also the cultural significance such practices may have held within Bronze Age communities, as well as the potential meanings attributed to the landscapes associated with them.

Taking Coppa Nevigata as a case in point, the community made extensive use of the wetland resources at the mouth of the Candelaro River. Archaeozoological evidence [83] points to diverse fishing activities supported by both fish remains and carried out both in the lagoon and the open sea [84]. In addition, turtle remains – both marine and terrestrial – as well as bird bones have been recovered [85]. Hunting also appears to have played a consistent role, particularly in the later Bronze Age phases (Subappennine period, 13th-12th centuries BCE), as shown by the notable presence of red deer remains [86].

These wild resources likely served not only as dietary supplements to the agropastoral base but also provided valuable secondary products (e.g. hides, antlers) that could be used locally or exchanged for external goods and materials. Beyond their utilitarian value, these practices may also have carried symbolic or social meaning. Hunting, in particular, may have served not only as a subsistence activity but also as an expression of status or social challenge, especially if access to certain animal-derived resources was socially restricted or unequally distributed within the community.

A further note is required regarding the mountainous areas, particularly the Gargano promontory. The distribution maps presented in this work reveal apparent gaps in archaeological evidence; however, recent studies – published or currently in publication – are shedding new light on the use of mountainous territories during the later phases of Prehistory, although the nature of this occupation remains difficult to define. In particular, reference is made to the systematic survey work conducted by A. Monaco and, more recently, by the Superintendency [87]. Moreover, despite its mountainous character, the Gargano region also features valleys and intramontane plains that would have been well suited to the needs of stable settlements. Therefore, unlike what has been observed for the inland territories of Abruzzo, this area could have supported a range of human activities – opportunistic (e.g. the acquisition of raw materials such as timber or flint), seasonal (e.g. transhumant pastoralism), or continuous throughout the year (e.g. permanent settlement).

Taking into account the diversification of communities and settlements discussed, a pivotal point for understanding landscape and its dynamics is its political structure. As regards the 2nd mill. BCE, the settlement pattern emerging in the area under scrutiny reflects a complex mosaic of coexisting lifeways, ranging from long-lived fortified sites to small open-air or seasonally occupied settlements. This diversity cannot be fully explained by traditional centre-periphery models, nor by rigid typologies of site hierarchy, even because communities could produce diverse political arrangements of space at the local scale. Rather, it suggests that space and society were organised through diversified relationships, in which different communities shaped and perceived the landscape both in diverse way and through reciprocal interactions – with the environment, with other groups, and with the material traces of past human activity.

Fortified settlements represented enduring landmarks within the landscape, often strategically placed along the coast or near lagoon systems. Yet, smaller, open-air settlements, often known only through surface finds and lacking evidence for fortification persisted. In certain areas – such as the northern coast of the Gargano – such sites appear to coexisted with fortified centres (without apparent conflict?), hinting at forms of spatial and social integration. In contrast, the area around Coppa Nevigata shows a more exclusive pattern: the absence of contemporary neighbouring settlements may reflect a form of territorial exclusion, possibly driven by competition over key resources such as access to wetlands or inland foraging zones, and in this case evidence of conflict exists [88].

These dynamics exemplify what can be conceptualised as intertwined lifeworlds [89] – a condition in which diverse communities, characterised by differing socio-political settings and economic strategies inhabited overlapping landscapes without necessarily converging into a single cultural framework. The

[83] Minniti 2012; Recchia *et alii* 2024a; Siracusano 2012.

[84] Given the limited evidence for vessel types and assuming an average speed of c. 3–4 kn under fair conditions, the c. 5 km passage from Coppa Nevigata to open sea would take ~40–55 minutes (Gustas and Supernant 2017; Whitewright 2011).

[85] Minniti *et alii* 2022; Siracusano 2012.

[86] De Grossi Mazzorin *et alii* 2017; Lucci 2022, p. 367; Minniti 2021.

[87] Monaco 2016; Pian *et alii* 2024.

[88] Cazzella and Recchia 2012, p. 264.

[89] Lucci 2023.

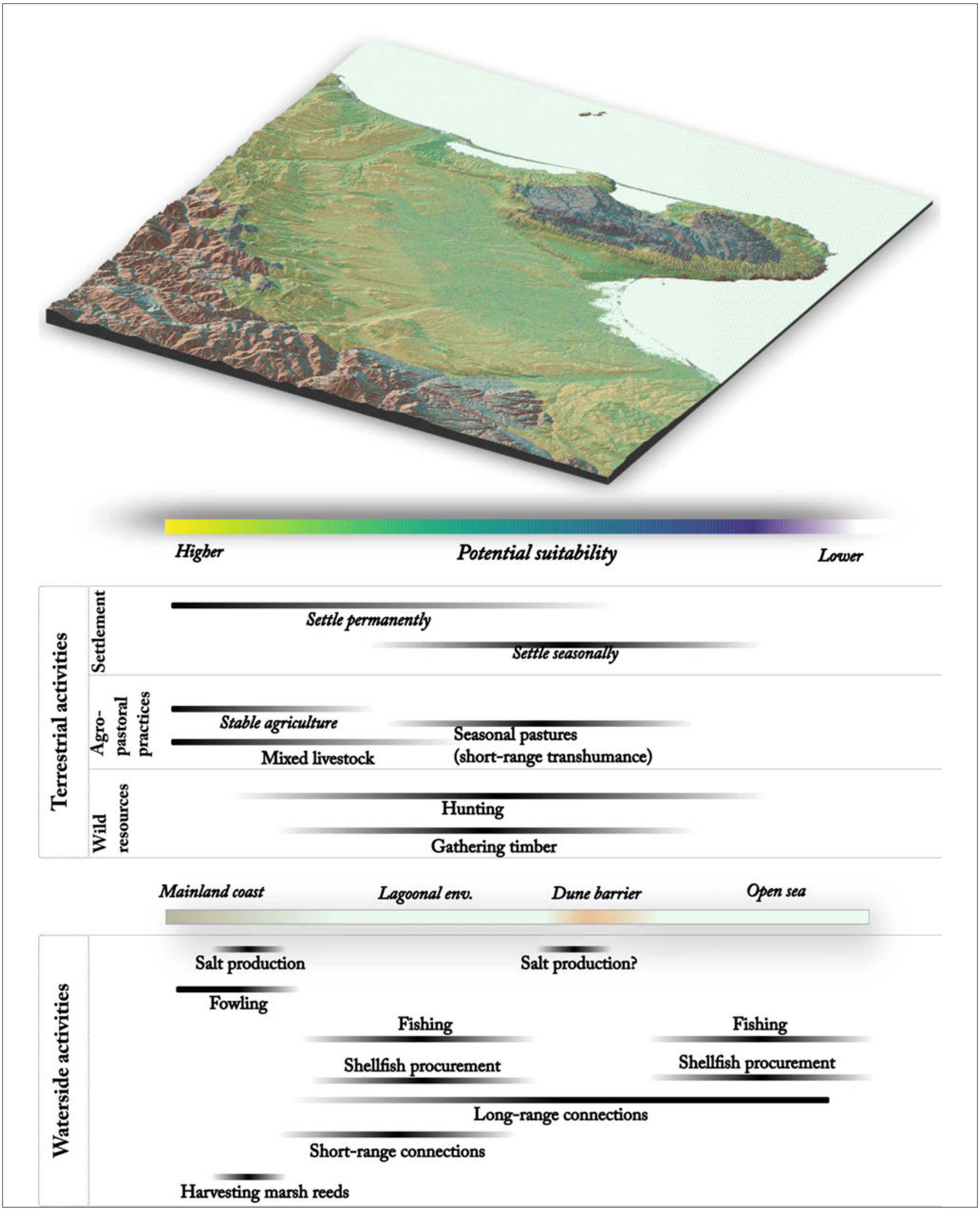

Fig. 16. - 3D visualisation of a cumulative MaxEnt suitability model for settlement distribution, integrating outputs from all three chronological phases. Green to yellow areas indicate higher modelled suitability values, potentially corresponding to zones of more intensive or potential persistent human use. Blue/fully transparent areas reflect very low or null suitability. The composite surface offers a synthetic view of long-term ecological attractiveness, highlighting areas where favourable conditions may have persisted over time. The bar below links different ranges of suitability to corresponding economic activities. Lines connect each activity to its estimated ecological threshold, offering an interpretive key to possible patterns of land use.

resulting landscape was neither fully segmented nor wholly unified, but rather a palimpsest of trajectories and interactions – woven together across time by human and non-human agencies alike.

To conclude, the mosaic landscapes of northern Apulia – ranging from the Subappennine hills to the coastal wetlands – hosted communities whose practices and perceptions of the environment changed considerably between the Copper and Bronze Ages. These communities did not merely adapt to ecological shifts, but actively contributed to reshaping their surroundings through a diverse range of productive strategies. From integrated agropastoral economies and the selective use of ecological niches to the emergence of specialised craft activities and long-distance exchanges, the archaeological and palaeoenvironmental records point to complex and dynamic interactions between people and landscape.

Compared to the inland zone of the Abruzzo region previously discussed, northern Apulia reveals significantly different *longue durée* trajectories in settlement patterns and relationships with places in the landscape. Over time, the meaning of these places evolved in close connection with the human activities performed within them. The interpretive model of landscape exploitation (fig. 16) suggests a broader range of potential land use compared to the scenario outlined for Abruzzo (fig. 9). This difference is partly explained by the region's environmental diversity, its proximity to the sea, and the relatively low elevation of its uplands – all of which facilitated access to a wide spectrum of environments.

It is particularly noteworthy that, although coastal areas near lagoons do not exhibit the highest ecological suitability for permanent settlement – at least according to the model – these areas nonetheless emerged as culturally and strategically significant. Their roles in shaping seascapes of connectivity – facilitating maritime routes and offering protection due to their marginal and difficult-to-access locations – contributed to their importance within local settlement systems as well as points of reference in long-distance networks across the Central Mediterranean. This role became increasingly prominent in later phases, as evidenced by the emergence of new centres, such as Salapia during the 1st mill. BCE, following the abandonment of Coppa Nevigata, which was likely caused by the silting of the lagoon [90].

Detailed case studies illuminate how niche construction operated at the local scale. Fortified centres or interventions in wetlands exemplify acts of perturbation, directly exploiting and shaping the environment to secure centrality in the landscape and long-term subsistence perspective of the community. By contrast, small hamlets or seasonal sites embody strategies of relocating economic activities, exploiting diverse niches without deep transformation but reinforcing flexible ties to the landscape. Meanwhile, the persistence of long-term occupations, such as lakeshores or coastal promontories, illustrates ecological inheritance. Communities persisted or repeatedly returned to such places not only because of their enduring ecological affordances, but also because they had already been reshaped by earlier practices. Fields once cleared, paths established, or landmarks created in the past structured the decisions of later groups, embedding cultural memory within the environment itself. In this sense, the concept of ecological inheritance draws attention to the ways in which landscapes preserve the cumulative effects of previous niche construction, shaping future choices as much as immediate needs or opportunities. Continuity of occupation is therefore not passive repetition, but the active re-engagement with niches already transformed into cultural as well as ecological resources.

2. Ethnographic insights

> "*One evening, sitting on a rock side-by-side with an older woman I knew well,*
> *indulging in the somewhat sentimental conversations which she much enjoyed,*
> *looking from the village to the forest lit up in the reds of the setting sun (one of*
> *the rare days when it was not raining), I thought the moment had come to make*
> *her say how much she liked the forest and regretted its passing, and so I asked*
> *her once more ... After long reflection she said wistfully that, yes, she liked the*
> *forest. 'Why?', I asked eagerly. 'Because you can cut it down,' she replied*" [91].

With the due caution required by ethnographic parallels, an attempt will be made to explore the ideological sphere, or at least to step outside our own. It is, of course, impossible to account for all the dynamics

[90] Susini *et alii* 2023.

[91] Bloch 1995, p. 65.

outlined above, but attention will be directed to selected processes.

For the 2nd mill. BCE in Apulia, evidence points to a marked expansion of open landscapes and a retreat of woodland (see § 2) – a process in which human activities likely played a central role through extensive deforestation, agricultural intensification, and the construction of enduring architectural features such as fortifications. These transformations cannot be seen merely as the ecological footprint of a growing population or the pursuit of economic productivity. Rather, they could be understood in ideological perspective.

Maurice Bloch's analysis of the Zafimaniry [92] offers a particularly valuable framework for thinking about such transformations. Among the Zafimaniry (eastern Madagascar), the act of clearing forest is never reduced to a technical intervention: it is an ideological process through which nature is progressively converted into social space. Trees are felled, soil is opened, and dwellings are established in a manner that materialises genealogical continuity. The visible structures of the landscape – houses, cultivated plots, megaliths – are thus read not only as evidence of subsistence but also as markers of collective identity and permanence. For Bloch, the forest is "clarified" by human action, and this clarification makes visible the historical presence of the community, transforming the landscape into a durable expression of collective agency. A more open landscape does not merely imply greater availability of pasture or arable land; it also entails enhanced visibility, control, and possible interactions.

Whether we consider the emergence of long-lived settlements during the 2nd mill. BCE in southeast Italy, these developments testify not only to an intensification of land use but also to the creation of new cultural landscapes in which environmental transformation, social organisation, and symbolic meaning were inseparably intertwined.

Another relevant aspect, briefly mentioned in the previous paragraphs, is the relationship – or rather the reflection – of kinship structures in the use of the spaces surrounding the community, and thus in the shaping of the landscape both in physical and in ideological-social terms. When we ask ourselves how the areas around a settlement might have appeared, and what their meanings were at different scales of distance, these aspects must also be taken into account.

[92] Bloch 1995.

Peter Gow's study of the Piro in Western Amazoni [93] provides one of the clearest ethnographic demonstrations of how kinship and landscape are inseparably entwined. For the Piro, subsistence practices are not merely directed toward survival but are the very means through which social relations are produced, remembered, and renewed. The most evident example is the system of gardens (*chacras*), which are never simply fields of cultivation but extensions of domestic life. Each couple establishes and maintains several gardens at once, each at a different stage of use: newly cleared plots, productive fields, and abandoned gardens gradually returning to forest: "*The native people of the Bajo Urubamba are slash-and-burn agriculturalists. Each year every married man, especially if he has children, is expected to dear a new garden in the forest for himself and his wife. The couple then plant this garden with a sequence of crops, depending on what they expect to need over the next few years. Gardens produce for more than a year, sometimes almost indefinitely, so each couple has a series of producing gardens scattered around the community*" [94]. This constant cycle means that around any settlement there is always a mosaic of plots that mirrors the life histories of the families who created them. The landscape is thus temporally and spatially shaped by the rhythms of domestic reproduction, each garden standing as a tangible trace of a couple's existence and of the kinship ties they sustain [95].

The produce of these gardens further underlines their social significance. Plantains, the everyday staple, are directly associated with kinship, while manioc, transformed into beer (*masato*), circulates widely within and beyond the village. Thus, the garden is not an isolated economic unit but part of a wider system of reciprocity and alliance, in which subsistence becomes a medium for the constant reproduction of social relationships.

Beyond the gardens, the surrounding forest is also a space dense with social meaning. Gathering activities – of fruits, fibres, and medicinal plants – connect people to specific places whose knowledge is passed on across generations. Alongside this, hunting and fishing play a crucial role in subsistence, yet their products are understood to come from beyond human agency: "*In addition to the work of gardening, men, and to a lesser extent women, are producers of game.*

[93] Gow 1995.

[94] *Ibidem*, p. 48.

[95] "Couple" intended as nuclear family.

Forest game, particularly the animals of remote inland areas, are the most desired food items, but river fish are the most commonly eaten. Unlike garden crops, the game animals of the forest and river exist outside of human agency. Humans do not create them nor do they work to multiply them. They are produced and multiplied through the agency afforest and river spirits, the 'owners' and 'mothers' of their respective domains. The game is produced as food by locating and then catching it" [96].

[96] Gow 1995, p. 49.

Taken together, gardens, abandoned plots, regenerating forests, gathering zones, and hunting grounds form what Gow calls *loci of kinship*. The vegetation pattern surrounding a village is not a neutral ecological arrangement but a visible record of genealogical relations. Every layer of the landscape is an embodiment of social memory: the abandoned garden recalls the labour of previous generations. It also testifies to the entanglement of anthropic spaces and those governed by non-human agents, together forming an undifferentiated lived-in landscape.

6.
Final remarks

The scientific question at the heart of this research project has its roots in the line of inquiry I pursued during my doctoral studies: to give a spatial and visually appreciable dimension to the activities carried out by prehistoric communities. The aim was to understand the function of spaces, the processes of interaction taking place within them, and their wider – often ideological – significance within cultural systems. It is important to recall in this respect that spaces are not only defined by their physical boundaries, but also by human behaviours that generate latent structures [1], subtle and difficult to perceive, yet accessible through the study of the spatial distribution of archaeological evidence.

During the doctorate, this perspective was applied primarily to intra-site contexts, most notably at Coppa Nevigata [2]. Whereas my doctoral research focused on the intra-site scale, this project expands that perspective to reconstruct a broader framework of human activities as they unfolded across the landscape, seeking to capture both the ecological and cultural dimensions of the lived-in environment.

As case study, Copper and Bronze Ages communities of southeast Italy have been selected, as a geographical and chronological framework that embraces crucial changes within the broader historical trajectories of Mediterranean societies. To achieve this goal, I have followed a multi-scalar and multi-proxy approach, integrating archaeological evidence, palaeoenvironmental data, economic information, and computational modelling.

At its core, the project has sought to move beyond a static or deterministic conception of landscape, adopting instead the interpretive frame of the *lived-in landscape* and engaging with the insights of Niche Construction Theory (NCT) [3]. In so doing, it has aimed not merely to reconstruct distributions of sites or economic practices but to capture the dynamic, recursive processes by which communities reshaped their ecological niches and transmitted them across generations.

The theoretical premise was that landscapes are both medium and outcome of human action. In line with NCT, humans are not passive recipients of environmental constraints but active niche constructors, altering soils, vegetation, hydrology, and social meanings in ways that persist as an "ecological inheritance". This framework justified the decision to investigate human–landscape interaction through a double lens: on the one hand, the mechanistic dimension, accessible through environmental modelling and quantification; on the other, the social dimension, accessed through contextual interpretation of practices, perceptions, and cultural meanings.

To reach these aims, the work proceeded in three main operational steps:

1. Dataset construction. The first challenge was to assemble a coherent macroregional dataset from uneven archaeological evidence. By deliberately avoiding rigid thresholds (e.g. sherd counts) and instead assessing contexts qualitatively, the dataset sought to preserve the widest possible signal of human presence. Even minimal traces can reveal practices, from seasonal resource procurement to enduring settlement.

2. Modelling and analysis. A suite of computational methods was employed to formalise spatial and temporal patterns.

MaxEnt, for example, allows us to identify the environmental variables most strongly associated with settlement choices. Rather than being seen as simple environmental constraints, these variables highlight the combinations of factors where communities acted most decisively as agents of ecological niche co-construction. Through practices such as cultivation, woodland clearance, or wetland management, they introduced perturbations that reshaped local ecologies, leaving forms of ecological inheritance that structured the options available to subsequent generations.

KDE and Cross-K analyses, which measure spatial clustering and interaction between site distributions

[1] Leroi-Gourhan 1984.
[2] Lucci 2022.
[3] Laland *et alii* 2016.

across phases, can likewise be framed within NCT. Persistent attraction patterns across time reflect ecological inheritance: the tendency of communities to return to, and reinforce, places already reshaped by previous occupation. Conversely, spatial repulsion or the emergence of new clusters suggests perturbation or relocation, pointing to moments when groups deliberately shifted their engagement with the environment, either to mitigate ecological stress or to pursue new social strategies.

SPD analysis of radiocarbon dates contributes a demographic dimension to this picture. Peaks and troughs in population trends can be linked to phases of stability or disruption in the processes of niche construction. Demographic growth often corresponds to the successful maintenance and expansion of constructed niches, while downturns may reflect the limits of existing strategies and the need for relocation or innovation. In this way, even demographic curves become indicators of how communities negotiated the long-term sustainability of their landscapes.

Taken together, these models illustrate that quantitative outputs are not merely descriptive or predictive. They are interpretive tools, providing a means to identify the dynamics of continuity and transformation in past landscapes. By embedding these results within NCT, the modelling process becomes integral to understanding how human agency reshaped the environment and how those changes, in turn, structured future possibilities.

3. Contextual interpretation. Crucially, models were never treated as deterministic outputs. Instead, they were re-read through case studies to capture the multi-scalar dynamics. The results reveal a trajectory marked by continuity and transformation. Certain ecological niches – wetlands, fertile plains, accessible coastal promontories – maintained their relevance across centuries, testifying to the persistence of ecological and cultural inheritance. At the same time, innovations in settlement form, economic practices, and perceptions of strategic places introduced new perturbations into the system, leading to reconfigurations of human presence in the landscape. Demographic fluctuations, as proxied by radiocarbon dates, further underline how communities adapted to broader climatic instabilities (e.g. the 4.2 ka event), sometimes abandoning niches, sometimes intensifying their exploitation.

By framing these results within NCT, the study highlights that landscape construction is a recursive process, meaning that the outcomes of an action feed back into the very conditions that shape future actions. Human groups not only adapt to environmental affordances but actively modify them, influencing subsequent generations. Agricultural practices, woodland clearance, and the building of long-lived centres all exemplify acts of niche construction. Their effects – from soil erosion to the persistence of social landmarks – constitute forms of ecological inheritance that shaped the choices of later communities.

In methodological terms, the adoption of MaxEnt has been central. While developed for species distribution modelling, in this project it was applied to human settlement patterns as a way of identifying the environmental covariates most relevant to past niche construction. By modelling suitability surfaces rather than merely mapping known sites, MaxEnt o opened a heuristic space for discussing not only 'what is known' but also "what could have been". The broader implication is that uncertainty has been embraced as a generative condition, a crucial aspect considering that archaeological data are inevitably fragmentary.

The "lived-in landscape" is thus not reduced to a series of site distributions, but emerges as a dynamic field of practices, memories, and ecological transformations.

In conclusion, this research contributes to three interrelated domains:

- For Italian prehistory, it provides the first large-scale modelling of Copper and Bronze Age settlement strategies in south-eastern Italy, revealing patterns of continuity, rupture, and innovation.
- For landscape archaeology, it demonstrates how computational modelling can be integrated with social theory to move beyond environmental determinism.
- For broader debates on human–environment interaction, it illustrates how Niche Construction Theory can be fruitfully adapted from evolutionary biology to archaeology, offering categories – perturbation, relocation, ecological inheritance – that illuminate the cultural construction of landscapes.

A further layer of interpretation has been introduced through the integration of ethnographic insights. While the archaeological record provides the material traces of past practices, and modelling formalises their spatial and temporal patterns, ethnography offers a means to restore the human and social dimensions that risk being obscured by purely quantitative approaches. Comparative case studies highlight how kinship, memory, and ideology are materially embedded in landscapes through practices of cultivation, circulation of food, and the meaning of places. These comparisons do not serve as direct explanations but as heuristic devices, enabling a more nuanced reading of archaeological patterns and reminding us that prehistoric landscapes were not only ecological settings but also genealogical archives, political and symbolic constructions.

A broader final reflection concerns the theoretical framework and the development of landscape archaeology – and, more generally, of archaeology and the practice of historical reconstruction. In recent decades, the application of quantitative approaches – from network analysis and geostatistics to the use of artificial intelligence and machine learning – has progressively intensified. This trend has been driven both by the epistemic curiosity of researchers, drawn to the potential of computational resources applied to archaeological data, and by funding systems that tend to privilege methodological innovation, often at the expense of more traditional studies, which nonetheless remain indispensable.

Yet there is the impression that the significant advancement of methodological tools has not always been matched by an equivalent deepening of theory. The risk is that historical reconstruction may turn into the mere description of models and graphs, rather than keeping at its core the understanding of human communities and their practices. Models, in fact, should represent a point of departure or a stimulus for further reflection, not a final outcome. In the past, much of the uncertainty that is now addressed through Bayesian or predictive models was elaborated through dialectics, discursive reasoning, understood as a critical and flexible practice capable of accounting for the complexity of collective behaviours. Perhaps it is precisely in this tension – between computational formalisation and interpretive openness – that today's challenge lies: ensuring that the power of quantitative methods does not overshadow theory, but instead revitalises and strengthens it.

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List of sites included in the quantitative analysis

Bibliographic references for each listed context are available through the project's published web map; see the QR code in Chapter 3 (fig. 3).

n	Site name	Region	Type of investigation	*Copper Age nd*	Early Copper Age 4th mill. BCE	Late Copper Age 3rd mill. BCE	*Bronze Age nd*	EBA 20th-16th c. BCE	MBA 15th-14th c. BCE	LBA 13th-12th c. BCE	FBA 11th c. BCE
1	Monte San Felice	Abruzzo	Surf. coll./Other								x
2	Le Mole 1	Abruzzo	Surf. coll./Other	x							
3	Castelnuovo - Monte Castello	Abruzzo	Surf. coll./Other	x							x
4	Luco - Strada 45	Abruzzo	Surf. coll./Other						x	x	x
5	Le Mole 2	Abruzzo	Surf. coll./Other						x	x	x
6	Angizia	Abruzzo	Surf. coll./Other						x		
7	Avezzano - Strada 6	Abruzzo	Surf. coll./Other						x	x	x
8	San Pelino - Masciarelli	Abruzzo	Surf. coll./Other	x							
9	Avezzano -Strada 8	Abruzzo	Surf. coll./Other						x	x	
10	Villino sor Paolo	Abruzzo	Surf. coll./Other	x							
11	Avezzano - Strada 10	Abruzzo	Surf. coll./Other							x	
12	Pozzo Sant'Angelo	Abruzzo	Surf. coll./Other								x
13	Pratovecchio	Abruzzo	Arch. exc.			x					x
14	Celano - Paludi	Abruzzo	Arch. exc.			x		x	x	x	x
15	Colle Restoppia	Abruzzo	Surf. coll./Other			x					
16	Il mulino	Abruzzo	Surf. coll./Other	x							
17	Trasacco 2	Abruzzo	Surf. coll./Other							x	x
18	Trasacco 1	Abruzzo	Arch. exc.			x		x	x	x	x
19	Fond'Jò	Abruzzo	Arch. exc.						x	x	x
20	San Rufino 1	Abruzzo	Surf. coll./Other						x	x	x
21	Cerchio - La Ripa	Abruzzo	Arch. exc.						x	x	x
22	Arciprete	Abruzzo	Surf. coll./Other								x
23	Balzone	Abruzzo	Surf. coll./Other			x			x		
24	Capazzano	Abruzzo	Surf. coll./Other			x					
25	Amplero	Abruzzo	Surf. coll./Other				x				
26	Ortucchio - strada 29	Abruzzo	Surf. coll./Other						x		
27	Collarmele - Madonna delle Grazie	Abruzzo	Surf. coll./Other	x							

→

28	Collemaggiore	Abruzzo	Surf. coll./Other								x
29	Ortucchio - Strada 28	Abruzzo	Arch. exc.		x	x			x	x	x
30	Venere - Restina	Abruzzo	Surf. coll./Other						x		x
31	Villa D’oro - Pescina	Abruzzo	Arch. exc.		x						
32	Il laghetto	Abruzzo	Arch. exc.						x	x	
33	Tussio	Abruzzo	Arch. exc.	x				x			
34	Piana Ripa	Abruzzo	Arch. exc.	x							
35	Laghetto di Santo Stefano di Sessanio	Abruzzo	Surf. coll./Other					x			
36	La Serpentana	Abruzzo	Surf. coll./Other			x					
37	Le Coste	Abruzzo	Arch. exc.		x	x		x	x		
38	Le Licinie	Abruzzo	Arch. exc.	x							
39	Aia	Abruzzo	Arch. exc.	x			x				
40	Laghetto di Caporciano	Abruzzo	Arch. exc.	x							x
41	Rocca Calascio	Abruzzo	Surf. coll./Other								x
42	Valle Cerenzana	Abruzzo	Arch. exc.			x					
43	Le Castagne	Abruzzo	Arch. exc.			x					
44	Piana di Macrano	Abruzzo	Arch. exc.	x							
45	Fosso di Santa Pelagia	Abruzzo	Arch. exc.	x				x			
46	Madonna del Campo	Abruzzo	Surf. coll./Other					x	x		
47	Colle San Salvatore	Abruzzo	Surf. coll./Other					x	x		
48	Colle Brignile	Abruzzo	Surf. coll./Other								x
49	Laghetto di Collepietro	Abruzzo	Surf. coll./Other			x		x			
50	Colle Santa Rosa	Abruzzo	Arch. exc.								x
51	Fonti San Callisto	Abruzzo	Arch. exc.	x							
52	La Fortellezza	Abruzzo	Arch. exc.	x					x	x	x
53	Madonna degli Angeli	Abruzzo	Arch. exc.						x	x	x
54	San Clemente	Abruzzo	Arch. exc.						x		
55	Fonte d’Amore	Abruzzo	Surf. coll./Other	x							
56	Torre De’ Passeri	Abruzzo	Arch. exc.					x			
57	Busciara	Abruzzo	Surf. coll./Other	x			x				
58	Catignano	Abruzzo	Arch. exc.				x				
59	Madonna del Freddo	Abruzzo	Surf. coll./Other	x							
60	Colle Longo - Roccascalegna	Abruzzo	Arch. exc.			x					
61	Lago di Pennadomo	Abruzzo	Surf. coll./Other						x		
62	Laghetto di Acquaspruzza	Molise	Surf. coll./Other				x				
63	Monte Marchetta 2	Molise	Surf. coll./Other				x				
64	San Giovanni	Abruzzo	Arch. exc.			x		x			
65	Monte Marchetta 1	Molise	Surf. coll./Other	x							
66	Morgia Quadra	Molise	Surf. coll./Other						x		
67	Pesco la Messa	Molise	Surf. coll./Other					x	x		
68	Fonte Tasca	Abruzzo	Arch. exc.								x
69	Castropignano	Molise	Arch. exc.							x	
70	Morgia Pietra Fenda	Molise	Surf. coll./Other					x			
71	Morgia Pietra Lumanna	Molise	Surf. coll./Other						x	x	
72	Oratino-La Rocca	Molise	Arch. exc.						x	x	x
73	Fonte Maggio	Molise	Arch. exc.					x	x	x	

→

74	Punta d'Erce	Abruzzo	Arch. exc.						x	x	
75	Chianelle	Molise	Surf. coll./Other					x			
76	Raiale	Molise	Surf. coll./Other					x	x	x	
77	Frascorivaldo	Molise	Surf. coll./Other					x	x	x	
78	Colle Folgo	Molise	Surf. coll./Other						x		
79	Tratturello	Molise	Surf. coll./Other				x				
80	Vallone Iannella	Molise	Surf. coll./Other	x							
81	Macchia Rotonda	Molise	Surf. coll./Other				x				
82	Macchia del Sorvo,	Molise	Surf. coll./Other	x			x				
83	S.Angelo	Molise	Surf. coll./Other						x	x	
84	S. Angelo	Molise	Surf. coll./Other	x							
85	Gradete	Molise	Surf. coll./Other			x	x				
86	Monte Castello	Molise	Surf. coll./Other						x		
87	Masseria Mammarella	Molise	Arch. exc.						x	x	
88	Masseria Vincelli	Molise	Surf. coll./Other	x							
89	Colle Masilli	Molise	Surf. coll./Other				x				
90	Bosco Difesa	Molise	Surf. coll./Other				x				
91	Piano Quadrato	Molise	Surf. coll./Other				x				
92	Contrada Vigna	Molise	Surf. coll./Other				x				
93	Masseria Verticchio	Molise	Surf. coll./Other				x				
94	Colle Ruggero	Molise	Surf. coll./Other						x		
95	Colle Arsano	Puglia	Surf. coll./Other						x	x	
96	Colle di Breccia	Puglia	Surf. coll./Other						x		
97	Tuppo della Guardiola	Puglia	Surf. coll./Other			x			x	x	
98	Malchieuti	Puglia	Surf. coll./Other						x		
99	Valle Cancelli	Puglia	Arch. exc.		x						
100	Località- Piano Navuccio	Puglia	Surf. coll./Other						x	x	x
101	Spineto	Puglia	Surf. coll./Other				x				
102	Località- Macello	Puglia	Surf. coll./Other						x		
103	Viarelle-Casa Capanna	Puglia	Surf. coll./Other				x				
104	Località- Avellana	Puglia	Surf. coll./Other						x		
105	Località- Mezzanola	Puglia	Surf. coll./Other						x		
106	Mass. la Marchesa	Puglia	Surf. coll./Other				x				
107	Loc. Alvanella	Puglia	Surf. coll./Other						x	x	
108	Mezzarazza	Puglia	Surf. coll./Other				x				
109	Località- Colle di Creta	Puglia	Surf. coll./Other			x		x			
110	Località- Sant'Agata	Puglia	Surf. coll./Other						x	x	
111	Pezze della chiesa 1	Puglia	Surf. coll./Other						x		
112	Piani di Lauria	Puglia	Surf. coll./Other	x					x		
113	Località- Masseria della Brecciara	Puglia	Surf. coll./Other						x	x	
114	Coppa delle rose	Puglia	Surf. coll./Other						x		
115	Località- Colle d'Arena	Puglia	Surf. coll./Other						x		
116	Masseria Magliano	Puglia	Arch. exc.					x		x	
117	Calcara	Puglia	Surf. coll./Other						x		
118	Robertacce	Puglia	Surf. coll./Other					x		x	x
119	Castello	Puglia	Arch. exc.				x				

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120	Località- Villa Merlino	Puglia	Surf. coll./Other						x	x	
121	Cuparone	Puglia	Surf. coll./Other						x	x	x
122	Posta Montaratro	Puglia	Surf. coll./Other					x			
123	Masseria Cuparoni	Puglia	Surf. coll./Other					x			
124	Casina Pirro	Puglia	Surf. coll./Other					x		x	
125	Masseria Rignanesi	Puglia	Surf. coll./Other				x				
126	Montedoro	Puglia	Surf. coll./Other					x			
127	Masseria Montaratro Svizzera	Puglia	Surf. coll./Other							x	x
128	Casina Marucci	Puglia	Surf. coll./Other	x				x	x	x	
129	Loc Cammarata	Puglia	Surf. coll./Other	x			x				
130	Masseria Cocca	Puglia	Surf. coll./Other					x			
131	Masseria Curato	Puglia	Surf. coll./Other					x			
132	Masseria Curato	Puglia	Surf. coll./Other	x							
133	Masseria Ricciardelli	Puglia	Surf. coll./Other	x			x				
134	Masseria Corvelli	Puglia	Surf. coll./Other					x			
135	Masseria Petruccelli B	Puglia	Surf. coll./Other	x							
136	Guadone	Puglia	Arch. exc.	x					x	x	
137	Masseria Petruccelli A	Puglia	Surf. coll./Other					x	x		
138	Masseria Pacifico	Puglia	Surf. coll./Other	x				x	x		
139	Coppa Sant'Annunzia	Puglia	Surf. coll./Other					x	x		
140	La Petrara	Puglia	Surf. coll./Other				x				
141	Deliceto loc. Chieffo	Puglia	Arch. exc.					x	x		
142	Tegole	Puglia	Arch. exc.		x	x					
143	Casina Barone II	Puglia	Surf. coll./Other			x		x		x	
144	Orto di Barone	Puglia	Surf. coll./Other					x			
145	Torrebianca	Puglia	Surf. coll./Other					x			
146	Podere Cifeli	Puglia	Surf. coll./Other					x			
147	Mass. Caldoli	Puglia	Surf. coll./Other			x	x				
148	Pozzo del Saligo	Puglia	Surf. coll./Other				x				
149	Torrione del Casone	Puglia	Surf. coll./Other			x					
150	Loc. Portata Casone	Puglia	Surf. coll./Other			x					
151	Masseria Fragella	Puglia	Surf. coll./Other	x							
152	Mezzana Quercia	Puglia	Surf. coll./Other			x		x			
153	Loc. Mezzanelle Brancia	Puglia	Surf. coll./Other	x				x			
154	Masseria Ponte Albanito	Puglia	Surf. coll./Other				x				
155	San Potito 1	Puglia	Surf. coll./Other				x				
156	Brancia Postiglione	Puglia	Surf. coll./Other	x				x			
157	Castelpagano	Puglia	Arch. exc.					x	x		
158	Posta Rivolta	Puglia	Arch. exc.					x			
159	Masseria Bozzelli	Puglia	Surf. coll./Other			x					
160	Cicerale	Puglia	Surf. coll./Other			x					
161	Valle Castagna 1	Puglia	Surf. coll./Other				x				
162	Masseria Torchiarelli	Puglia	Surf. coll./Other				x				
163	Torre Mileto	Puglia	Arch. exc.		x			x	x	x	x
164	Herdonia	Puglia	Arch. exc.				x				
165	Gravina	Puglia	Surf. coll./Other				x				

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166	Salvetere	Puglia	Surf. coll./Other				x				
167	Monte d'Elio	Puglia	Surf. coll./Other				x				
168	Torre Calarossa	Puglia	Surf. coll./Other						x		
169	Monte Granata	Puglia	Arch. exc.						x	x	x
170	I Lamioni	Puglia	Surf. coll./Other				x				
171	Chiancata Civita	Puglia	Surf. coll./Other	x				x	x	x	
172	Casale Crisetti	Puglia	Surf. coll./Other				x				
173	Foce Capoiale	Puglia	Surf. coll./Other	x					x		
174	San Vito	Puglia	Surf. coll./Other				x				
175	Il Castello	Puglia	Surf. coll./Other								x
176	Coppa Castedda	Puglia	Surf. coll./Other						x	x	
177	Vallone San Giovanni	Puglia	Surf. coll./Other				x				
178	Masseria Santa Tecchia	Puglia	Surf. coll./Other	x							
179	Chiancata Avatra	Puglia	Surf. coll./Other				x				
180	Coppa Masselli	Puglia	Surf. coll./Other				x				
181	Coppa Nevigata	Puglia	Arch. exc.					x	x	x	x
182	Masseria Cupola	Puglia	Arch. exc.					x			
183	Santa Lucia	Puglia	Surf. coll./Other	x			x				
184	Macchito	Puglia	Surf. coll./Other					x			
185	sette poste	Puglia	Surf. coll./Other					x	x		
186	Madonna di Ripalta	Puglia	Arch. exc.						x	x	x
187	Macchia a Mare	Puglia	Arch. exc.		x		x				
188	Loc. Finizia	Puglia	Surf. coll./Other				x				
189	Punta Manaccora	Puglia	Arch. exc.					x	x	x	x
190	La Bufalara	Puglia	Surf. coll./Other				x				
191	Le Chianche	Puglia	Arch. exc.					x			
192	Castello Pignatelli	Puglia	Arch. exc.						x	x	
193	Masseria caterina	Puglia	Arch. exc.					x			
194	Carluva	Puglia	Arch. exc.					x			
195	Punta la Molinella	Puglia	Arch. exc.						x	x	
196	Canne	Puglia	Arch. exc.						x	x	x
197	Il Cavone	Puglia	Arch. exc.					x	x		
198	Madonna del Petto	Puglia	Arch. exc.					x	x	x	x
199	San Lazzaro	Puglia	Surf. coll./Other	x							
200	Masseria Melodia	Puglia	Surf. coll./Other				x				
201	Garagnone	Puglia	Arch. exc.					x			
202	Monte Marano	Puglia	Surf. coll./Other				x				
203	Masseria di Cristo	Puglia	Surf. coll./Other				x				
204	Masseria Filieri	Puglia	Surf. coll./Other				x				
205	Masseria Fornasiello	Puglia	Surf. coll./Other					x			
206	Jazzo Fornasiello	Puglia	Arch. exc.					x			
207	Fontana Filippi	Puglia	Surf. coll./Other			x		x	x		
208	Jazzo Martora 2	Puglia	Surf. coll./Other				x				
209	Jazzo Lama Cantarella	Puglia	Surf. coll./Other				x				
210	Masseria San Mauro	Puglia	Surf. coll./Other				x				
211	Casa San Paolo	Puglia	Surf. coll./Other						x		

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212	Jazzo Portico	Puglia	Surf. coll./Other				x				
213	Borgata Murgetta 2	Puglia	Surf. coll./Other				x				
214	Capo Colonna	Puglia	Arch. exc.					x	x	x	x
215	Trani II	Puglia	Arch. exc.						x		
216	Malerba	Puglia	Surf. coll./Other								x
217	Padula Priore	Puglia	Surf. coll./Other				x				
218	Masseria Castello	Puglia	Surf. coll./Other				x				
219	Murgia Catena	Puglia	Surf. coll./Other				x				
220	Lamia Recchia	Puglia	Surf. coll./Other				x				
221	Giovinazzo - San Salvatore	Puglia	Arch. exc.					x	x		
222	Masseria Rasizzi	Puglia	Surf. coll./Other				x				
223	Piscina rossa	Puglia	Surf. coll./Other			x		x			
224	i Casalicchi	Puglia	Surf. coll./Other				x				
225	Casino don cataldo/contrada tesoro	Puglia	Surf. coll./Other								x
226	Lago dell'Arciprete	Puglia	Surf. coll./Other				x				
227	Parco Procino	Puglia	Surf. coll./Other				x				
228	Loseto/Picone	Puglia	Surf. coll./Other				x				
229	Dannetta	Puglia	Surf. coll./Other					x			x
230	Santa Candida	Puglia	Arch. exc.		x	x		x			
231	Torre Monacello	Puglia	Surf. coll./Other				x				
232	Bari Centro Storico	Puglia	Arch. exc.					x	x	x	
233	Masseria del Porto	Puglia	Arch. exc.		x						
234	Montelarino	Puglia	Surf. coll./Other						x	x	
235	Collenza	Puglia	Surf. coll./Other				x				
236	San Leo	Puglia	Surf. coll./Other		x						
237	San Pietro - Capurso	Puglia	Arch. exc.		x						
238	Masseria Greco II	Puglia	Surf. coll./Other					x			
239	Pentimone	Puglia	Surf. coll./Other			x					
240	Parco San Nicola	Puglia	Arch. exc.		x	x					
241	Frassineto Mass. Dalfino	Puglia	Surf. coll./Other					x			
242	Tomegna	Puglia	Arch. exc.				x				
243	Mass. Ospedale	Puglia	Surf. coll./Other				x				
244	Annunziata	Puglia	Arch. exc.							x	x
245	Masseria Annunziatella	Puglia	Surf. coll./Other				x				
246	Punta la Penna	Puglia	Arch. exc.					x	x	x	
247	La Giunta	Puglia	Surf. coll./Other				x				
248	Trisore/ Masseria Moretto	Puglia	Surf. coll./Other				x				
249	Monte Nuovo	Puglia	Surf. coll./Other			x					
250	Madonna delle Grazie I	Puglia	Surf. coll./Other		x						
251	Lama Rossa	Puglia	Surf. coll./Other			x					
252	Madonna delle Grazie II	Puglia	Arch. exc.		x						x
253	Cozzo di Marziotta	Puglia	Arch. exc.					x	x	x	x
254	Via La Quacquera	Puglia	Surf. coll./Other					x			
255	Le Rene	Puglia	Surf. coll./Other			x					
256	Monte Ferraro	Puglia	Surf. coll./Other					x			
257	Monte Ferraro 2	Puglia	Surf. coll./Other					x			

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258	Mola di Bari	Puglia	Arch. exc.						x	x	
259	Gravina di Monsignore	Puglia	Surf. coll./Other								x
260	Monte San Michele	Puglia	Surf. coll./Other								x
261	Scoglio del Tonno	Puglia	Arch. exc.					x	x	x	x
262	San Domenico	Puglia	Arch. exc.					x	x	x	
263	Masseria belvedere	Puglia	Surf. coll./Other		x						
264	Monopoli - Centro storico	Puglia	Arch. exc.					x	x	x	
265	Porto Perone	Puglia	Arch. exc.					x	x	x	x
266	Grofoleo	Puglia	Arch. exc.		x						x
267	San Giovanni	Puglia	Surf. coll./Other				x				
268	Masseria Montefusco	Puglia	Surf. coll./Other				x				
269	Masseria Palombara	Puglia	Surf. coll./Other					x	x	x	x
270	Monte Salete	Puglia	Arch. exc.								x
271	Fornovecchio	Puglia	Surf. coll./Other					x			
272	Figazzano	Puglia	Surf. coll./Other				x				
273	Torre Castelluccia	Puglia	Arch. exc.						x	x	x
274	Sisto	Puglia	Surf. coll./Other							x	x
275	Marinelli	Puglia	Surf. coll./Other	x			x				
276	Egnazia	Puglia	Arch. exc.					x	x		
277	Carperi	Puglia	Surf. coll./Other						x	x	
278	Barbagiulo	Puglia	Surf. coll./Other				x				
279	Monte Gianecchia	Puglia	Surf. coll./Other	x				x	x		x
280	Masseria Gianecchia Grande	Puglia	Surf. coll./Other					x			
281	Masseria Amati	Puglia	Surf. coll./Other				x				
282	Potere	Puglia	Surf. coll./Other				x				
283	Femminamorta	Puglia	Surf. coll./Other				x				
284	Ibernia Piccola	Puglia	Surf. coll./Other					x			
285	Cisternino	Puglia	Surf. coll./Other				x				
286	Monte d'Amico	Puglia	Surf. coll./Other					x			
287	Iacumin	Puglia	Surf. coll./Other				x				
288	Pico	Puglia	Surf. coll./Other				x				
289	Masseria Carella	Puglia	Surf. coll./Other								x
290	Bagnara	Puglia	Arch. exc.					x	x	x	x
291	Monte D'Alessio/Monte Alessio	Puglia	Surf. coll./Other					x	x		
292	Ibernia grande B	Puglia	Surf. coll./Other				x				
293	Foggianuova	Puglia	Surf. coll./Other				x				
294	Pozzo la Foggia	Puglia	Surf. coll./Other					x	x		
295	Peppeturro	Puglia	Surf. coll./Other				x				
296	Masseria Marangiulo	Puglia	Surf. coll./Other				x				
297	Masseria Chiancudda	Puglia	Arch. exc.					x	x	x	x
298	Monte le Pergole	Puglia	Surf. coll./Other					x			
299	Misus	Puglia	Surf. coll./Other	x							
300	Masseria Piccola	Puglia	Surf. coll./Other						x	x	
301	Monte Piantella	Puglia	Surf. coll./Other					x	x	x	
302	Tesoro	Puglia	Surf. coll./Other							x	x
303	Masseria Capitolo	Puglia	Surf. coll./Other					x	x	x	

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304	Panza	Puglia	Surf. coll./Other				x				
305	Maselli	Puglia	Surf. coll./Other						x		x
306	Zaccano	Puglia	Surf. coll./Other					x			
307	Progne	Puglia	Surf. coll./Other					x		x	
308	Monte Agrisani A	Puglia	Surf. coll./Other				x				
309	Santa Sofia	Puglia	Arch. exc.	x						x	x
310	La Specchia	Puglia	Surf. coll./Other	x				x	x		
311	Monte Agrisani B	Puglia	Surf. coll./Other					x			
312	Parco della Foggia	Puglia	Surf. coll./Other	x				x		x	x
313	Villa Lo Parco	Puglia	Surf. coll./Other					x			
314	Masseria Cirasulo	Puglia	Surf. coll./Other					x			x
315	Acquarossa	Puglia	Surf. coll./Other					x			
316	Sant'Alpino	Puglia	Surf. coll./Other							x	
317	Carestia	Puglia	Surf. coll./Other					x			
318	Rissiedi	Puglia	Arch. exc.						x	x	
319	Masseria Taberne	Puglia	Surf. coll./Other							x	
320	Rosa Marina	Puglia	Surf. coll./Other		x						
321	monticelli	Puglia	Arch. exc.				x				
322	Le Fiatte	Puglia	Arch. exc.	x			x				
323	Monte la Concezione	Puglia	Surf. coll./Other							x	
324	Terragne	Puglia	Arch. exc.				x				
325	Bocca di Borraco	Puglia	Arch. exc.				x				
326	Paretone	Puglia	Surf. coll./Other								x
327	Torre Santa Sabina	Puglia	Arch. exc.							x	
328	Masseria Li Turri	Puglia	Arch. exc.							x	x
329	Torre Guaceto	Puglia	Arch. exc.					x	x		
330	Torre Castiglione	Puglia	Arch. exc.					x			x
331	Scogli di Apani	Puglia	Arch. exc.					x			
332	Muro Maurizio	Puglia	Surf. coll./Other					x			
333	Gallico	Puglia	Surf. coll./Other				x				
334	Torre Testa	Puglia	Surf. coll./Other				x				
335	Scalo di Furno	Puglia	Arch. exc.						x	x	x
336	Punta Le Terrare	Puglia	Arch. exc.					x	x		
337	Torre dell'Alto	Puglia	Surf. coll./Other					x			
338	Punta Aspide	Puglia	Surf. coll./Other				x				
339	Madonna dell'Alto	Puglia	Surf. coll./Other							x	x
340	Le Pazze	Puglia	Arch. exc.						x	x	
341	Masseria Vecchia	Puglia	Surf. coll./Other								x
342	San Donato	Puglia	Surf. coll./Other					x	x		
343	Cavallino	Puglia	Arch. exc.					x			
344	Serra delle Fontanelle	Puglia	Surf. coll./Other				x				
345	Stanzie	Puglia	Surf. coll./Other				x				
346	San Giovanni Piscopo	Puglia	Surf. coll./Other				x				
347	Spigolizzi	Puglia	Arch. exc.					x			
348	Falconiera	Puglia	Surf. coll./Other				x				
349	Masseria fano	Puglia	Arch. exc.					x			

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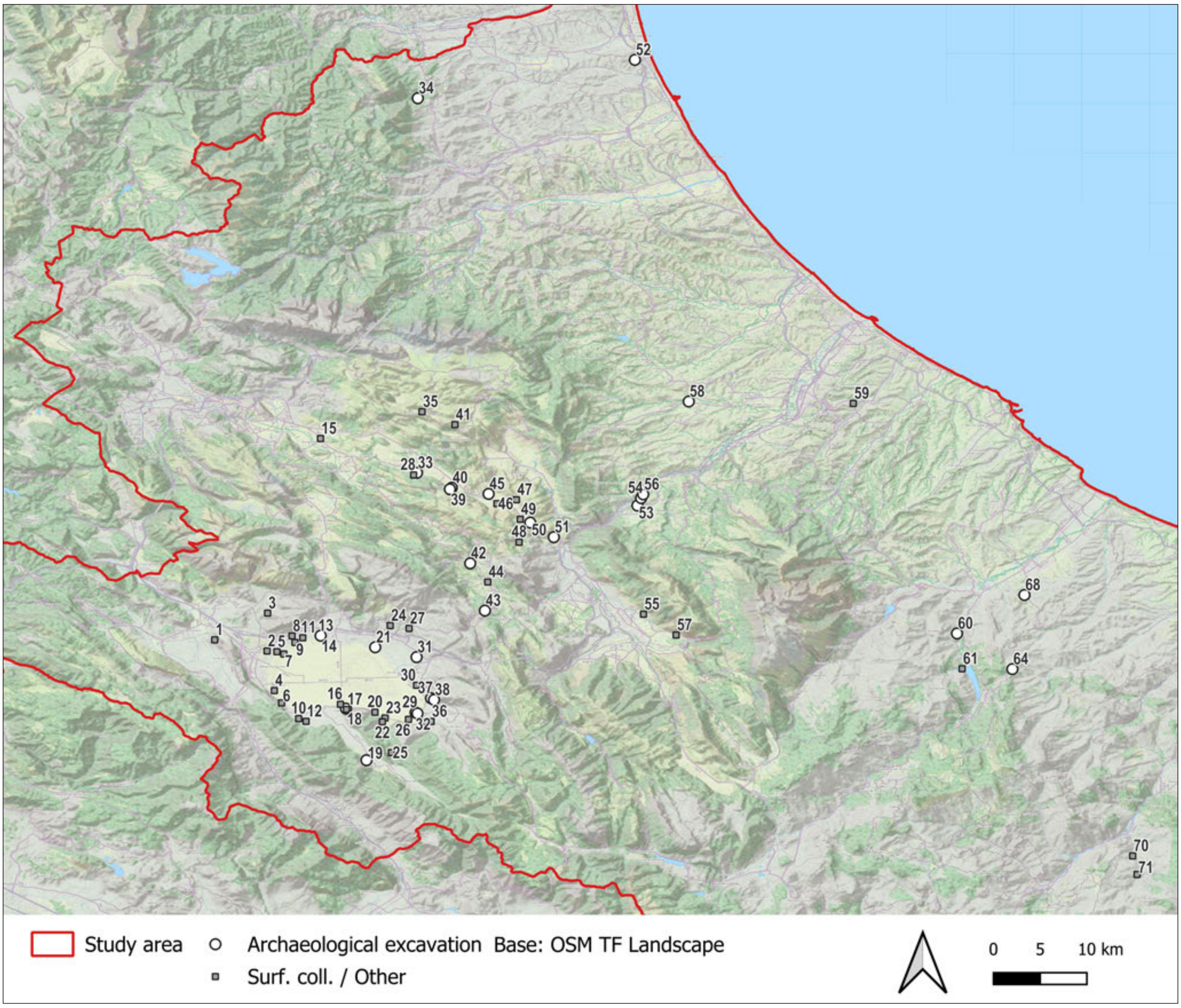
350	Pozzo Mauro	Puglia	Surf. coll./Other				x				
351	Masseria Schiatta	Puglia	Surf. coll./Other				x				
352	Murge - villaggio	Puglia	Surf. coll./Other				x				
353	Le Cesine	Puglia	Arch. exc.				x				
354	Vereto	Puglia	Surf. coll./Other				x				
355	Santa Maria di Leuca	Puglia	Arch. exc.						x	x	x
356	Diso	Puglia	Surf. coll./Other				x				
357	Rocavecchia	Puglia	Arch. exc.						x	x	x
358	Torre Sant'Andrea	Puglia	Arch. exc.				x				
359	Masseria Consalvi	Puglia	Surf. coll./Other				x				
360	Porto Badisco	Puglia	Arch. exc.						x		
361	Salapia	Puglia	Arch. exc.	x				x	x		
362	Alma Dannata	Puglia	Surf. coll./Other				x				
363	San Vito	Puglia	Arch. exc.		x	x					
364	Vasche Napoletane	Puglia	Arch. exc.	x				x	x		
365	Masseria Faralla	Puglia	Surf. coll./Other					x			
366	Vieste - Via G.B. Vico	Puglia	Arch. exc.		x						
367	Torre Sfinale	Puglia	Surf. coll./Other		x						
368	Ficora della Morra	Molise	Arch. exc.						x		
369	Tenuta Nola	Molise	Arch. exc.					x			
370	Li Schiavoni	Puglia	Arch. exc.							x	

Tables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Study area
Archaeological excavation
Base: OSM TF Landscape
Surf. coll. / Other
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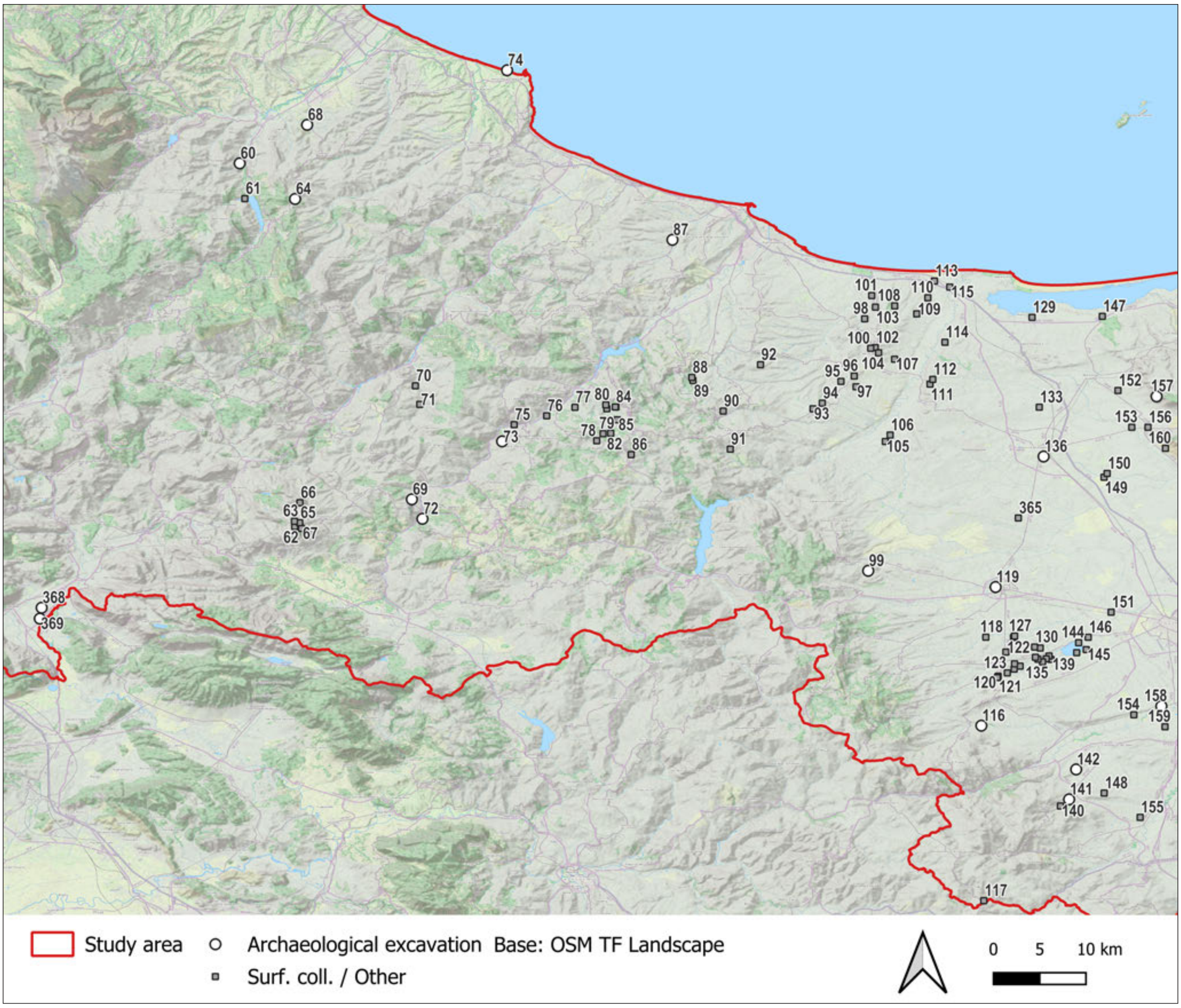
5
10 km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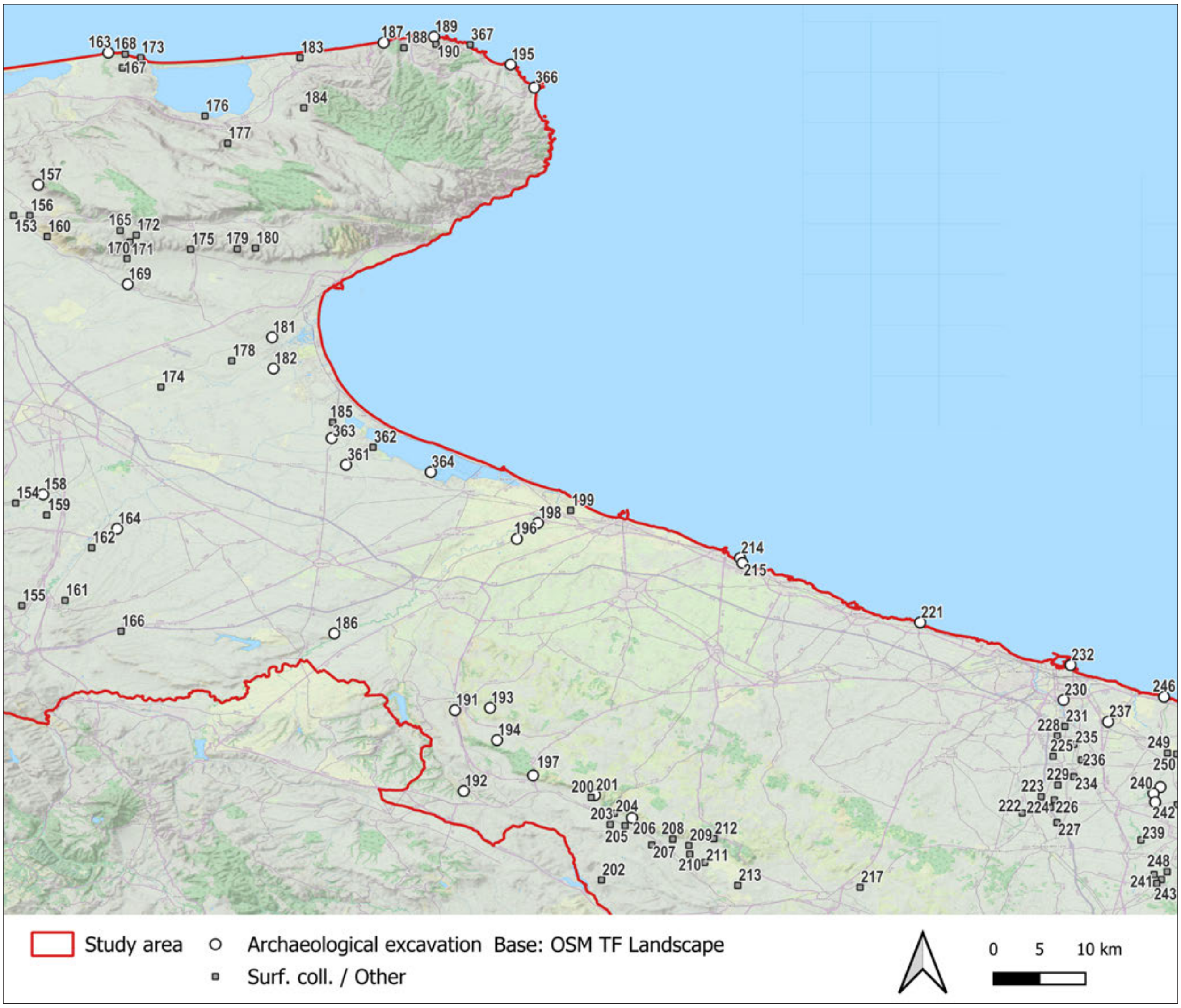
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Archaeological excavation
Surf. coll. / Other
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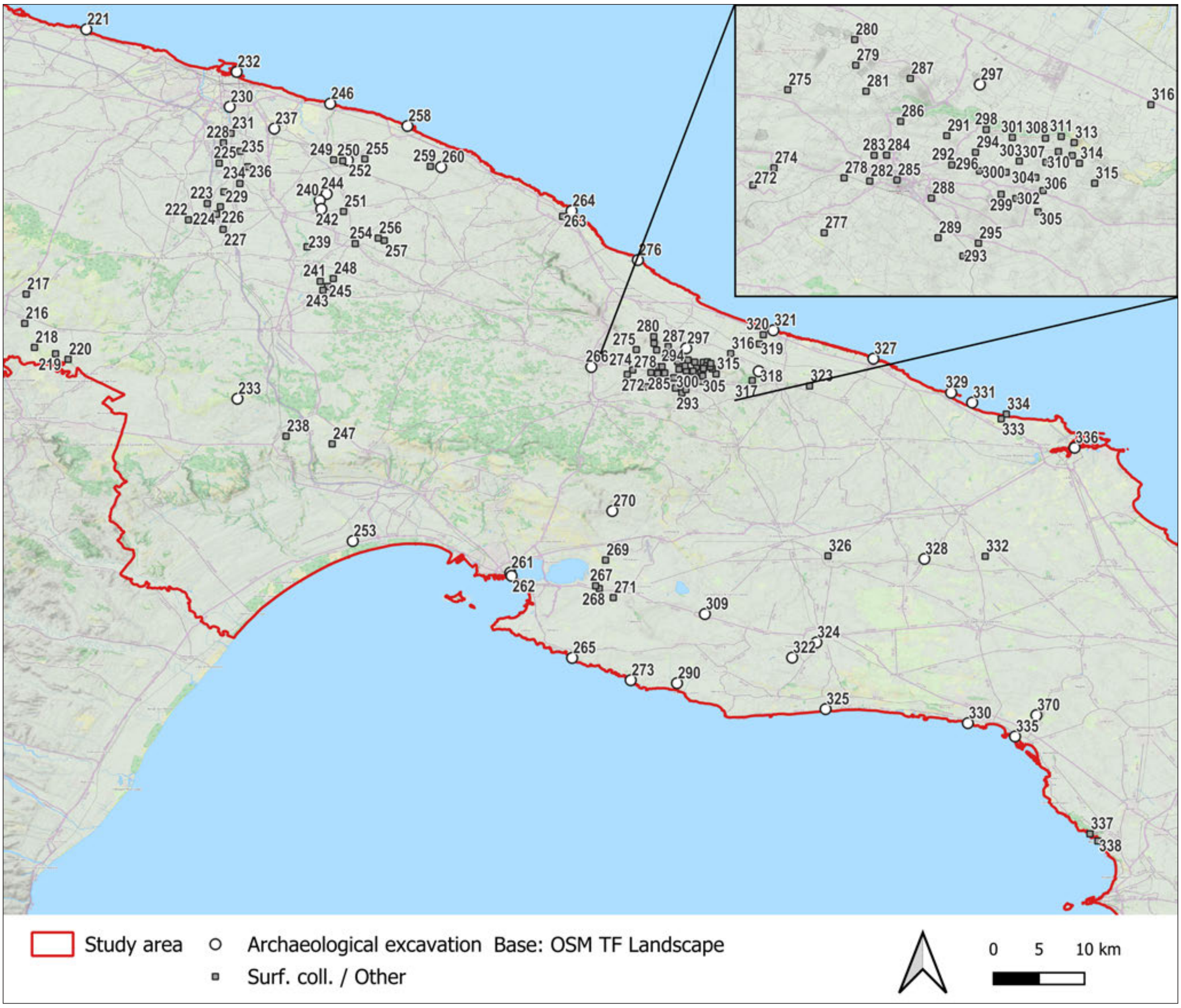

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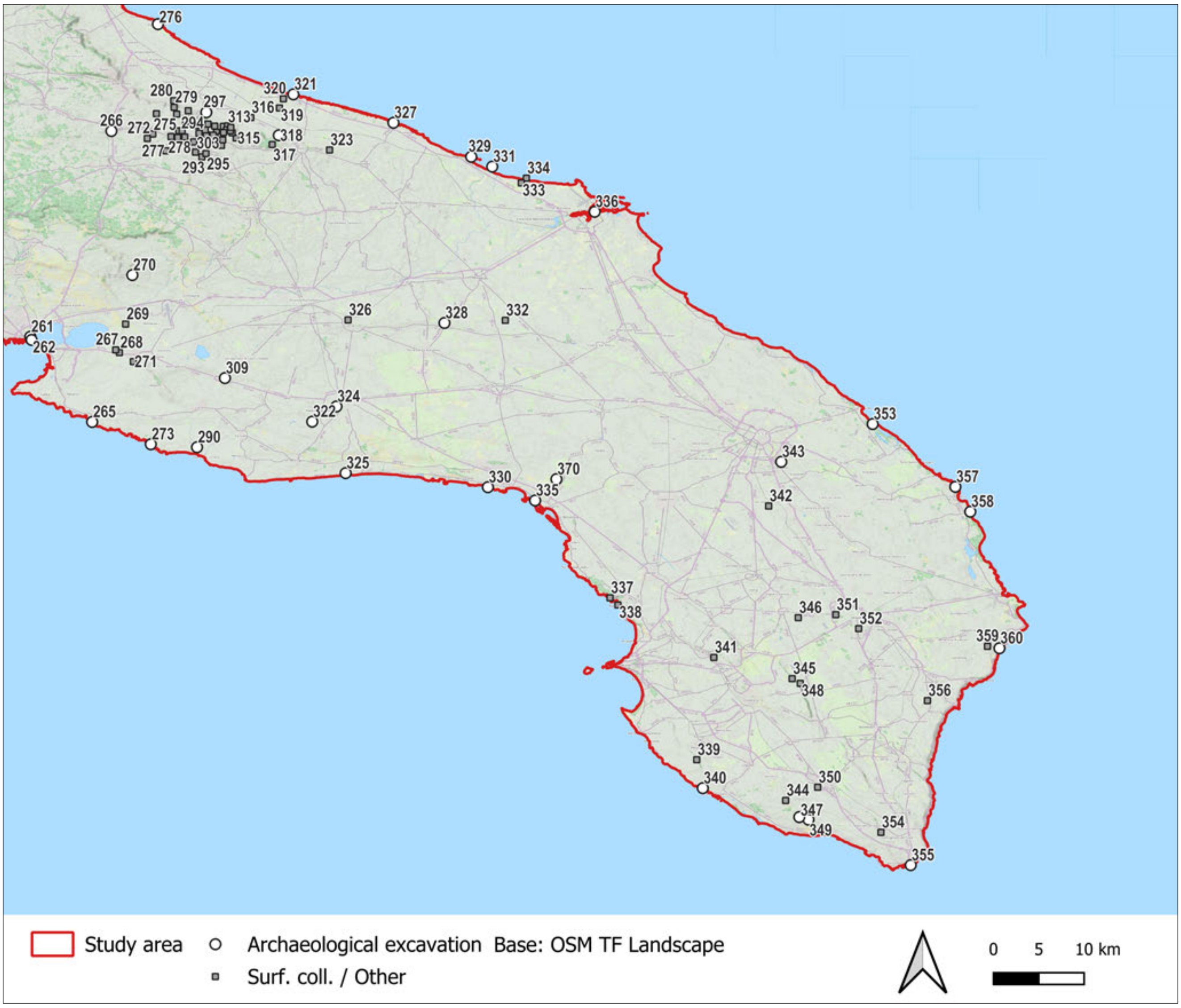
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Study area
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